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A NEW APPROACH TO MODELING THE COST OF OWNERSHIP FOR AIRCRAFT S--ETC(U)

AUG 81 K E MARKS, H G MASSEY, B D BRADLEY F49620-77-C-0023

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A New Approach to Modeling the Cost of Ownership for Aircraft Systems

Kenneth E. Marks and H. Garrison Massey
with Brent D. Bradley and John Lu

August 1981

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Illustrates estimation of support investment costs and recurring operations and support costs through a Model for estimating Aircraft Cost of Ownership (MACO), which also provides a framework for future research. MACO is an outgrowth of an earlier evaluation of the strengths and weaknesses of the most widely used aircraft life cycle cost models. It combines new algorithms for major, maintenance-related costs with formulas drawn from existing models for other cost elements. MACO relates a full set of ownership cost elements to component level reliability and maintainability characteristics and to aircraft design, operations, logistics, and deployment parameters, although the MACO equations would have to be reorganized before they could be used to estimate costs according to the cost structure of the latest Cost Analysis Improvement Group (CAIG) guide. MACO computes resource quantities in units that can be related directly to Air Force programming categories, including base maintenance manning (by work center), depot manning, and recoverable spares inventory levels. Output and input parameters accommodate annual changes in system parameters and operating conditions such as component reliability and aircraft inventory size and activity rates. pp. (Author)

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Kenneth E. Marks ~~and~~ H. Garrison Massey
~~with~~ Brent D. Bradley ~~and~~ John Lu

August 1981

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PREFACE

This report describes an approach to estimating and analyzing the ownership costs of Air Force aircraft systems in the form of an analytic Model for estimating Aircraft Cost of Ownership (MACO). This model is designed to generate total systems cost estimates as a function of aircraft component-level maintainability and reliability characteristics plus other aircraft design, logistics, operational, and deployment variables. It stems from earlier Rand research on the methods and applications of life cycle analysis in which several important deficiencies were noted in the models most widely used in the Air Force—deficiencies that significantly impair their ability to generate reliable estimates of the budgetary and other resource costs of ownership.

MACO incorporates many improvements over other aircraft life cycle cost models, but it is only a step toward meeting the full need. It is described here in terms of a complete set of algorithms, cost elements, variable definitions, and data sources. Coefficients are provided for most of the algorithms except those for aircraft depot maintenance. The model has not, however, been put in computer code, nor has it been validated as a whole. In its present form, MACO is most valuable as a framework to guide future research efforts on improved cost-of-ownership estimating techniques. Given the necessary inputs, the model may be useful for estimating and analyzing situations that require both sensitivity to detailed maintainability and reliability of design choices and a total cost estimate.

The research on MACO was undertaken while the Air Force and OSD were evaluating numerous changes to the policies and practices that control the preparation and use of life cycle analysis. Most notably, the OSD Cost Analysis Improvement Group (CAIG) published a revised guide of standard cost elements for operating and support costs* just after we completed work on MACO. (The original CAIG Guide had been used in developing the MACO cost elements.) The changes in cost element definitions do not affect MACO's principles and estimating approaches. They would require, however, that MACO's equations be reorganized before they could be used to estimate costs expressed in the new cost elements. The differences between MACO and the CAIG guide and a cross-walk for them are described in Appendix D.

*Office of the Secretary of Defense, Cost Analysis Improvement Group, *Aircraft Operating and Support Cost Development Guide*, 15 April 1980. Another important source document for MACO, AF Regulation 173-10, *USAF Cost and Planning Factors*, has also been replaced and is now AFP 173-13, *Planning Factors Guide*.

A

SUMMARY

Life cycle analysis has received considerable attention in the Air Force system acquisition management process as a mechanism for helping to control the increasingly high cost of acquiring and owning modern weapon systems. Despite this attention and use of life cycle analysis in many different areas of the acquisition process, many observers agree that it has not reached its full potential. Among the limiting factors are significant inadequacies in the concepts, tools, and supporting data for analyzing life cycle costs, particularly ownership costs.

This report describes a model, MACO (Model for estimating Aircraft Cost of Ownership), which illustrates a new approach for estimating ownership costs and, equally important, provides a framework for future research on that subject. MACO stems from earlier Rand research[1] that evaluated the strengths and limitations of the most widely used aircraft life cycle cost models. The evaluation emphasized ownership costs and applied as a main criterion the ability of the models to generate reliable estimates of total aircraft system budgetary costs and manpower demands. Estimates of total cost are not required for all life cycle analysis applications; in some instances estimates that simply indicate cost differences among alternative aircraft or subsystems (relative costs) are sufficient. It is necessary to know total costs to conduct tradeoffs properly between current acquisition costs and future ownership costs. Total costs must also be known when budgetary comparisons or projections of ownership cost are to be made. This evaluation of current models examined the sensitivity of the models to a wide range of cost driving factors (related to operation, maintenance, deployment, and the like) and the extent to which the models represented causal relationships (including Air Force resource requirements determination procedures and allocation processes). We found the models to be lacking on all of these items, as well as others.

Development of an entirely new model having all of the desirable features would be a very large and long term undertaking and beyond the scope of our present research resources. Therefore, we adopted the tactic of developing an interim model that would demonstrate an improved estimating *approach* and would build upon and extend the capabilities offered by three models evaluated in the earlier research: The Logistic Support Cost (LSC) model and the set of cost factor models, BACE and CACE, described in Air Force Regulation 173-10, *USAF Cost and Planning Factors* (since superseded by Air Force Pamphlet 173-13, *Planning Factors Guide*). These models were coupled with a fully defined set of ownership cost elements to provide a starting point for MACO.

MAJOR FEATURES OF MACO

MACO provides an integrated set of algorithms that yields an estimate of full ownership cost for a complete aircraft system as a function of aircraft component level maintainability and reliability characteristics plus other inputs describing aircraft design, operations, logistics, deployment, and several Air Force policy variables. MACO is an attempt to combine the visibility of component repair and related activities offered by the LSC model with the total

[1]Kenneth E. Marks, H. Garrison Massey, Brent D. Bradley, *An Appraisal of Cost Models Used in Life Cycle Cost Estimating for USAF Aircraft*, R-2287-AF, October 1978.

system breadth offered by the BACE/CACE models. As currently structured, the model uses maintainability and reliability inputs at the aircraft component level (e.g., line replaceable units and shop replaceable units). Thus, it applies mainly to design tradeoffs and other ownership cost analyses that occur from late in concept validation through full scale development and procurement of new weapon systems. The model also applies to analyses of modification proposals for in-service aircraft.

The cost elements used in MACO are structured to meet the general requirements of the OSD Cost Analysis Improvement Group (CAIG) and are defined in terms consistent with the USAF appropriation/budget categories and the Accounting System for Operations. The cost elements therefore provide a direct link between MACO and the language and data of the USAF programming, budgetary, and accounting systems.

Like the LSC model, MACO operates at the aircraft component level and traces the flow of resources through the maintenance process. In MACO, however, components are treated explicitly at the line replaceable unit (LRU) and shop replaceable unit (SRU) levels, and the flow of maintenance processes is expanded to include scheduled maintenance and servicing activities as well as unscheduled maintenance. Maintenance manhour requirements are generated by work center and then translated into total manpower requirements. The base maintenance manpower algorithms are patterned after the needs of tactical aircraft but can be readily modified for other aircraft types. New algorithms are also provided in MACO for base maintenance manpower, depot maintenance, and base materials.

For many cost elements MACO uses existing algorithms or other simple formulations. Estimates for consumable materials are generated in MACO either as a function of recoverable items cost or, for depot material only, as a function of repair hours and recoverable items unit cost. Estimates for spare engines are prepared with the LSC model equations and support equipment costs are generated with estimating relationships prepared by AFLC. Nearly all of the non-maintenance-related cost elements of MACO—including wing operations, installations support, training, medical, other support investment. POL and miscellaneous O&M—were taken directly from the BACE/CACE models. Most of the algorithms for these cost elements relate either to manpower or to activity rate variables.

The primary output of MACO is a set of estimates of total incremental costs expressed in *constant* dollars (in a year selected by the user). The model has been structured to estimate many of the intermediate resources, such as direct maintenance manhours, used to derive the final costs. These intermediate resources are often the subject of management concern and are important components of many life cycle analyses. The output of MACO also includes measures of supply effectiveness associated with the recoverable spares computations. Both the inputs and outputs of MACO are structured to accept time (annual) variations in system characteristics and operating conditions, including the buildup of an aircraft inventory and the maturation of reliability characteristics.

LIMITATIONS OF MACO AND RECOMMENDATIONS FOR FUTURE RESEARCH

MACO is a step toward the development of a satisfactory model of aircraft systems ownership cost. It is, however, an interim model, with several important limitations. For one, it has not been validated in the sense of having been operated with a full set of inputs and having its outputs compared with known values. MACO is also affected by limitations in the state of the art for ownership cost estimation. One needed improvement is greater consistency in the definition of individual cost elements. The cost elements called for by the CAIG and used in MACO do not adequately reflect the different influences on Air Force budget requirements stemming from resource demands that are driven directly by weapon systems (e.g., crew pay and allowances) as contrasted with demands driven largely by commodity management and forcewide considerations. Assuring greater comparability in cost elements is an important subject for future research.

Research is also needed to further improve estimating accuracy by increasing the fidelity with which individual estimating relationships and algorithms represent actual causal relationships and resource allocation procedures.

Another limiting factor for MACO and for the development of improved estimating algorithms for maintenance-related costs is the lack of an integrated historical data base at the aircraft component level. Historical information on component reliability and maintainability relevant to base maintenance is generally reported by work unit code, while depot level maintenance and recoverable spares information is recorded by stock number. Unfortunately, there is no standard reference to relate the two recording systems and the match must be done on an ad hoc basis at a given time. Development of consistent cross-walks among the maintenance-related data systems should be a priority item for future research.

One of the principal objectives of MACO is to provide a framework for research on ownership costs. This research should include the development of a more flexible model—one capable of accommodating input data at the LRU/SRU level for the portions of an aircraft that are of a particular interest in a given situation and more aggregate estimates for the remainder of the aircraft. This would increase the range of situations in which the model would be useful and reduce the need for a full range of very detailed inputs. Conceptually, such flexibility would require the model to be structured around alternative modules for each of the various combinations of aircraft subsystems and cost elements. Two modules would suffice for many combinations: one using detailed inputs and algorithms, say at the LRU/SRU level, and a second operating at the two-digit work unit code level or at the level of the standard operating cost factors found in AFP 173-13. Some of the needed flexibility is incorporated in MACO. It is structured around interchangeable algorithms, and alternative base maintenance manpower algorithms are provided that illustrate the use of varying levels of input detail. These are rudimentary capabilities, however, that require considerable expansion if a fully flexible model is to be provided. Interchangeable algorithms and the use of different levels of inputs are demonstrated in the aggregated base-maintenance manpower algorithms provided as an alternative in MACO.

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I. INTRODUCTION

Life cycle analysis has received considerable attention in the Air Force weapon system acquisition management process, principally as a mechanism for controlling the increasingly high costs of operating, maintaining, and otherwise supporting modern weapon systems. It is widely believed that ownership costs can be significantly influenced by systems design, performance, operational, and logistics choices made during the system acquisition process. Life cycle analysis offers a means for explicitly weighing the consequences of those choices and for making tradeoffs among system performance objectives and the temporally and fiscally different components of life cycle cost (LCC)—development, procurement, and operations and support (ownership).

The concepts and techniques of life cycle analysis are applied in many different facets of the system acquisition process. These include, for example, the screening of broad weapon system alternatives; evaluating specific design choices; establishing Air Force support postures and policies; evaluating contractor proposals and making source selections; forecasting budgetary and other support resource requirements for both new and in-being weapon systems; and evaluating proposed changes (modifications) in weapon system design, performance, or support characteristics. Life cycle cost considerations are also included in the OSD Cost Analysis Improvement Group (CAIG) appraisal of weapon systems that require approval by the Defense Systems Acquisition Review Council (DSARC). Despite the range of situations to which life cycle analysis is applied, many observers agree that its potential has yet to be fully realized. Some of the limiting factors are institutional, relating in part to the incentives of those who must make tradeoffs between performance and cost or between acquisition cost and ownership cost, and in part to the difficulties of firmly linking the results of life cycle analysis to the allocation of resources in the programming and budgeting process. Another set of limiting factors includes the inadequacies of the concepts, tools, and data available to support life cycle analysis. Although these inadequacies affect all components of life cycle cost to some degree, they are particularly apparent in the estimation and analysis of ownership costs. This latter subject, in the context of aircraft weapon systems, is the frame of reference for the present study.

This report describes the principal features and algorithms of a new Model for estimating Aircraft Costs of Ownership (MACO).

MOTIVATION FOR THE DEVELOPMENT OF A NEW MODEL

Nearly all life cycle analyses are prepared, at least in part, with one or more life cycle cost models and thus reflect the strengths and weaknesses of the basic methods (and supporting data) of the models. An earlier portion of Rand's research on life cycle analysis applications and methods evaluated the most commonly used LCC models.[1] Particular attention was given to those models applicable to the estimation of ownership costs. The principal criterion was the usefulness of the models for estimating the budgetary and other resource cost

[1]Kenneth E. Marks, H. Garrison Massey, and Brent D. Bradley, *An Appraisal of Cost Models Used in Life Cycle Cost Estimating for USAF Aircraft*, R-2287-AF, October 1978.

implications of proposed changes in an aircraft system's performance, operational, logistics, or other support characteristics. This is a demanding criterion and one that is not necessarily a requisite for all applications of life cycle analysis; some *comparative* analyses may require only consistent estimates of the difference between systems or subsystems (e.g., relative costs). The criterion of *total* cost is applicable, however, to a broad class of situations involving tradeoffs between current acquisition costs—development and procurement—and future ownership costs. The criterion also applies, more generally, to any situation involving budgetary comparisons or projections of ownership costs. Of related concern was the sensitivity of the models to aircraft performance and physical design characteristics and to various operational and support characteristics—collectively called "cost driving factors"—that would probably affect cost outcomes. The models included in the evaluation were:

BACE and CACE (from AFR 173-10, now AFP 173-13)
Logistics Support Cost Model (LSC)
Logistics Composite Model (LCOM)
MOD-METRIC
AFM 26-3 Manpower Standards
AFLC Depot Maintenance Cost Equations (AFLCP 173-4)
DAPCA (A Rand model for development and procurement cost of aircraft)
PRICE (An RCA proprietary model for avionics development and procurement cost)

Not surprisingly, we found that the existing models do not provide a satisfactory capability for generating estimates of total ownership cost. For the most part, these models were designed either to provide an indication of relative cost differences or to highlight a selected area of ownership cost without reference to the total. We noted several important deficiencies in the models including:

1. Inconsistent and often ambiguous definitions of the cost elements included, which makes it difficult to relate model outputs to budgetary and other resource programming/accounting categories or to empirically confirm or refute their reasonableness.
2. Insensitivity to many of the important cost driving factors—particularly those relating to Air Force support and institutional policies—and poor representation of causal relationships governing the resource demands and costs of aircraft systems.
3. Inadequate distinction between intermediate resource demands (e.g., maintenance manhours) and final resources and their dollar costs (e.g., maintenance personnel and their pay and allowances).
4. Inconsistent treatment of individual cost elements, confusing the analysis of cost effects when the mix of ownership resources is changed (that is, a dollar's worth of one resource may not be equivalent to a dollar's worth of another).

The model evaluation report shows in detail how these deficiencies can be responsible for inadequate cost estimates.[2] In sum, the models we evaluated fail, either individually or collectively, to provide a broadly satisfactory ownership cost estimating capability. And because of the differences in definitions and estimating techniques, no straightforward combination of the most satisfactory elements of the collection of models is possible. We therefore concluded that we needed a new model.

Development and validation of an entirely new model that would overcome the deficiencies cited above and incorporate numerous other desirable features would be a very large and

[2] Ibid., especially pp. 40-42.

long-term undertaking, one that is well beyond the scope of the resources we had available. We believed, however, that some important near-term improvements could be made and that these could be set in a framework that could usefully guide development of an even more powerful ownership cost model. In particular, we felt that sensitivity to component and subsystem detail, which is needed for application to design tradeoff studies, could be combined in a common modeling framework with the more comprehensive cost element coverage that is needed for making tradeoffs between competing systems.

To this end, we adopted the approach of building upon, modifying, and extending the capabilities offered by the three most widely used aircraft LCC models: the Logistics Support Cost (LSC) model and the BACE/CACE tandem of squadron operating cost models.[3] The best features of these models and several new algorithms were combined to form the new model, MACO.

MACO: AN INTERIM MODEL

We refer to MACO as an interim model because we wish to emphasize that the model does not meet all the needs of an aircraft system cost of ownership model. Additional capabilities are needed and should be developed by the Air Force and OSD cost analysis communities. (These are discussed in Section V of this report.) We have provided the overall design for a model that moves significantly toward those capabilities, but in itself it is not complete. The model has not been validated as a whole nor has it been implemented in computer program form, but it is well beyond the conceptual stage and does demonstrate an improved approach for generating estimates of total cost that reflect real-world practices and activities. Equally important, we have sought to provide a frame of reference for continuing research on improved estimating techniques.

MACO was designed primarily with applications to tactical aircraft systems in mind, and for some cost elements the algorithms represent only tactical aircraft systems; but the general approach used for these may suggest how substitute algorithms could be derived for other types of aircraft systems. We have also restricted the scope of the model in the sense that we have concentrated on estimating techniques for the cost of ownership. Acquisition costs—research and development (R&D) and system investment—are, of course, also important in most LCC estimates. The mix of component detail and overall system characteristics data needed to estimate ownership costs is usually compatible with the data requirements for estimating acquisition costs. However, the techniques used to generate the acquisition cost estimates—parametric models, engineering estimates, or actual contractor quotes—may be entirely different.

As currently structured, MACO provides a great deal of visibility at the aircraft component (LRU/SRU) level. This requires rather detailed inputs that are generally not available for a new aircraft until late in concept validation or during full scale development. Some provisions have been made, however, for more aggregate inputs; and the basic elements of a model flexible

[3]The LSC model is described in Headquarters Air Force Acquisition Logistics Division (AFLC), *Logistics Support Cost Model User's Guide*, August 1976. The BACE and CACE models are described in: Department of the Air Force, *USAF Cost and Planning Factors* (U), AFR 173-10, February 6, 1975, with changes through May 2, 1977, Vol. I (For Official Use Only). AFR 173-10 has since been superseded by AFP 173-13, *Planning Factors Guide*, and the BACE models have been replaced by the Cost Oriented Resource Estimating (CORE) model. The CORE model is similar to CACE. See also Marks, Massey, and Bradley, pp. 19-23, for a description of the characteristics of all three models.

enough to be used more widely throughout the acquisition cycle (or after the system is operational) are discussed in the concluding section of the report.

ORGANIZATION OF THE REPORT

Section II provides an overview of the model, including its structure and flow, and brief descriptions of the approaches taken to base maintenance manpower, depot maintenance, and maintenance material. The reader not concerned with specific design details and algorithms should find that Secs. II and V provide a general sense of the concept and main features and limitations of MACO. Sections III and IV describe the structure, algorithms, and data sources of MACO in detail. This information is intended primarily for analysts who will actually use the model as well as those concerned with research on ownership cost methods. Section III deals with the three major maintenance-related cost elements (Base Maintenance Manpower, Depot Maintenance, and Maintenance Material) to which most of our effort was devoted. Section IV deals with the other ownership cost elements, for which MACO uses algorithms adopted wholly or substantially from the LSC, BACE, and CACE models.

The text of the report ends with Section V, which summarizes the progress achieved with MACO, the limitations of the model as we see them, and suggestions for future research. Among the needs cited are those of increasing consistency and comparability among cost elements, increasing our understanding of causal relationships within the Air Force activities to be modeled, integration of maintenance-related data bases, and greater capability to bridge between very detailed estimating procedures and more aggregative procedures. We also offer suggestions for the design of a flexible model to provide this bridging capability.

Four appendixes complete the report. Appendix A defines the content of the cost elements used in MACO. Appendix B defines the variables used in the MACO equations, and Appendix C lists each of the MACO estimating equations in a form that should facilitate computer programming. Appendix D shows how the MACO cost element definitions relate to the OSD Cost Analysis Improvement Group cost element structure now in use.

II. OVERVIEW OF MACO

DEVELOPMENT APPROACH

The general concept followed in developing MACO was to provide an integrated set of algorithms that would allow the analyst to go from a rather detailed set of aircraft design, logistics, and other support and deployment variables to a statement of the total resources and absolute costs of ownership implied by those variables. Our approach was to construct an interim model that built upon and extended the capabilities offered by the LSC and BACE CACE models, which, coupled with an explicitly defined set of ownership cost elements, are the starting points for MACO.

Cost Elements

The cost elements define part of the model structure and provide a map of the portion of total ownership costs treated in the model. MACO uses a set of ownership elements specifically developed to be compatible with the Air Force budget (or Force and Financial Program) and the Accounting System for Operations. These elements, which are listed in Table 1 and defined in Appendix A, were derived from some published by the Logistics Management Institute for the OSD Cost Analysis Improvement Group (CAIG).[1] We developed the definitions during our earlier research on the evaluation of LCC models.[2] The April 1980 revisions to the CAIG's O&S cost element structure were published after work on MACO was complete, but we have provided a means of translating the MACO elements into the current CAIG elements in Appendix D.

Our modified cost elements were defined in more detail and have specific links with the budgeting process and accounting system. The definitions include terms used in budgeting and accounting, such as program elements, appropriations, element of expense and investment codes, and functional account codes. Cost elements based on these definitions provide cost tracking from weapon system ownership cost estimates to the planning, programming, and budgeting system and, in some instances, to eventual operating expenditures. With current models it is usually not possible to do this, because the categories used for estimating are abstract and conceptual and have little or no subsequent linkage to the programming process and to the manpower and budget/accounting data systems. The redefined cost elements are also intended to be compatible with current knowledge about the factors that drive such indirect costs as Installations Support and Personnel Support and Training.

Table 1 shows that for some cost elements we developed new estimating techniques for MACO, and for others we adopted estimating techniques from other models or extant methods. It also indicates that six cost elements included in the CAIG guide are omitted from MACO. These are elements for which we could neither identify nor develop suitable methods (in the short term) or elements whose appropriateness in an aircraft cost of ownership estimate we were uncertain about.

[1]Norman E. Betaque, Jr. and Marco K. Fiorello, *Aircraft System Operating and Support Costs: Guidelines for Analysis*, Logistics Management Institute, March 1977, p. 28. The CAIG guidelines for aircraft systems have changed in detail since MACO was completed, but the underlying principles and general structure are quite similar.

[2]Marks, Massey, and Bradley (1978), pp. 10-15.

Table 1

ELEMENTS OF COST OF OWNERSHIP COVERED BY MACO

Cost Element	Derivation of Algorithms: New	Adopted	Excluded
Support Investment			
Support Equipment		X	
Training Equipment and Services			X
Documentation			X
Initial Spares	X		
Spare Engines		X	
Facilities			X
WRM			X
Operations and Support			
Wing Operations			
Aircrews		X	
Command Staff		X	
POL		X	
Security		X	
Other Wing Manpower		X	
Miscellaneous O&M		X	
Base Level Maintenance			
Maintenance Manpower	X		
Maintenance Material	X		
Miscellaneous O&M		X	
Installations Support		X	
Depot Maintenance			
Manpower	X		
Material	X		
Depot Supply			X
Second Destination Transportation			X
Personnel Support and Training			
Individual Training		X	
Health Care		X	
PCS		X	
Sustaining Investments			
Replenishment Spares	X		
Modifications		X	
Replenishment Support Equipment		X	
Training Ordnance		X	

The LSC and BACE/CACE Models

When joined together, the LSC and BACE/CACE models provide an approximation of a total ownership cost model. A simple merger would not yield a very useful model, because some areas would overlap, and there would be several important gaps in cost element coverage; but both models have properties of value in designing a new ownership cost model.

Among the features of the LSC model are (1) the sensitivity it provides to aircraft reliability and maintainability design characteristics, (2) the visibility it offers of subsystem demands for direct logistics resources (e.g., maintenance manhours and spare parts), and (3) its first order representation of the flow of both base level and depot level logistics processes. The model does not stand by itself as an ownership cost model, however. It centers on maintenance and maintenance support activities and excludes many other important elements of ownership cost. Moreover, its simple and generally linear estimating algorithms fail to take account of many variables that affect the translation of direct resource demands into estimates of total cost. An important limitation of LSC, in our view, is that direct maintenance manhours are not converted into estimates of whole manpower requirements; and it is these estimates that are critical to the generation of total costs. Notwithstanding these limitations, LSC provides a very useful conceptual approach to the modeling of logistics demands and processes.

The BACE and CACE models provide some of the breadth in coverage of ownership costs missing from LSC, particularly those related to squadron and wing operations (as contrasted to maintenance-related activities). These models are also more usefully aligned with the categories of the Air Force programming and budgetary systems.[3]

Both models calculate costs for a typical aircraft squadron, based on such variables as the *primary authorized aircraft (PAA) per squadron, annual flying hours per aircraft, manpower* requirement per squadron, and various cost factors. The models provide very little sensitivity to aircraft design characteristics or cost-driving factors other than those mentioned above. Like LSC, BACE and CACE do not stand alone as satisfactory ownership cost models.

An early step in the development of MACO was to merge LSC and BACE/CACE to provide a rough mapping of algorithms for the principal elements of ownership cost. This crude hybrid was then decomposed and algorithms were screened, then adopted, modified, or omitted. Some algorithms were carried over directly into MACO, principally cost algorithms of BACE/CACE related to squadron and wing operations and miscellaneous support. The general approach to maintenance-related resource requirements determination, including subsystem and component visibility, was adopted from LSC. However, new algorithms were developed or taken from other Air Force sources for many maintenance and nonmaintenance activities and resources, including personnel. This was necessary to (1) provide sensitivity to a greater range of logistics and manning policy variables, (2) more faithfully reflect the underlying process by which Air Force agencies determined the requirements for the resources involved, and (3) provide a basis for converting direct resource requirements to estimates of absolute cost. The structure, information flow, and principal computational features of MACO resulting from this synthesis are discussed below.

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[3]The BACE (Planning, Programming and *B*udgeting *A*nnual *C*ost *E*stimating) model is used for programming and budgeting exercises. The CACE (*C*ost *A*nalysis *C*ost *E*stimating) model is used for life cycle cost exercises and weapon system comparisons. The models are similar and, as will be described later, both were useful in developing MACO.

STRUCTURE AND COMPUTATIONAL FEATURES OF THE MODEL

Figure 1 depicts the computational structure of MACO and traces the primary information flows through that structure. In the discussion that follows, we provide a brief description of the flow to give a sense of how the model would operate and the nature of its outputs. We then turn to a description of the computational approach used to represent the major resource categories and cost elements.

Information Flow

As indicated in the left hand side of Fig. 1, four sets of primary input data[4] are used in MACO to specify (1) the maintainability and reliability characteristics of aircraft LRU and SRU components; (2) the operational and activity rate variables for the aircraft; (3) the servicing, inspection, and other logistics support variables for aircraft; and (4) reliability, maintainability, and logistics support variables for engines. These inputs are used to compute the number of hardware failures and the number of scheduled and unscheduled repair actions and other maintenance actions. We use these results, along with LRU/SRU data and operational parameters, to compute the base and depot maintenance workloads. The workloads are the main inputs to the computations of maintenance manning for the depot and for those portions of base maintenance that are sensitive to weapon system requirements. We also use operations data in the manning calculations, particularly for portions of the base maintenance organization to which Air Force manpower standards apply.

Operations data inputs are used in the computation of the number of wing operations personnel. These personnel, combined with those of base maintenance, then are used to estimate the number of personnel required for installations support and formal training.

Two nonpersonnel resource quantities are also computed: recoverable spares and spare engines. The recoverable spares—both initial investment and replenishment—are estimated from the LRU/SRU input data, using a simplified version of the AFLC D041 recoverable items requirements system. The engine input data are used to generate estimates of whole spare engine requirements, using the failure rate and overhaul driven algorithms of the LSC model.

The estimates of manning requirements and of recoverable spares and spare engines are converted into dollar costs through the application of pay and allowance factors, unit prices, and miscellaneous cost factors as appropriate for each cost element. A separate computation is made for base and depot maintenance materials, principally economic order quantity (EOQ) consumables, as a function of recoverable spares costs. Similarly, support equipment costs are separately estimated, using an AFLC-developed algorithm that relates these costs to the flyaway cost of the aircraft. The cost of petroleum, oil, and lubricants (POL) is estimated as a function of flying hours, as in the BACE/CACE model.

Outputs of the Model

The final outputs of MACO are estimates of dollar costs expressed in the cost elements discussed earlier and listed in Table 1. The estimates of individual resource quantities for personnel, recoverable spares, and spare engines used to generate some of these costs are also

[4]Input data are also required for cost factors, conversion of manhours to personnel, and the like. These are generally constant from one aircraft design to the next, although they are separately addressable in MACO.

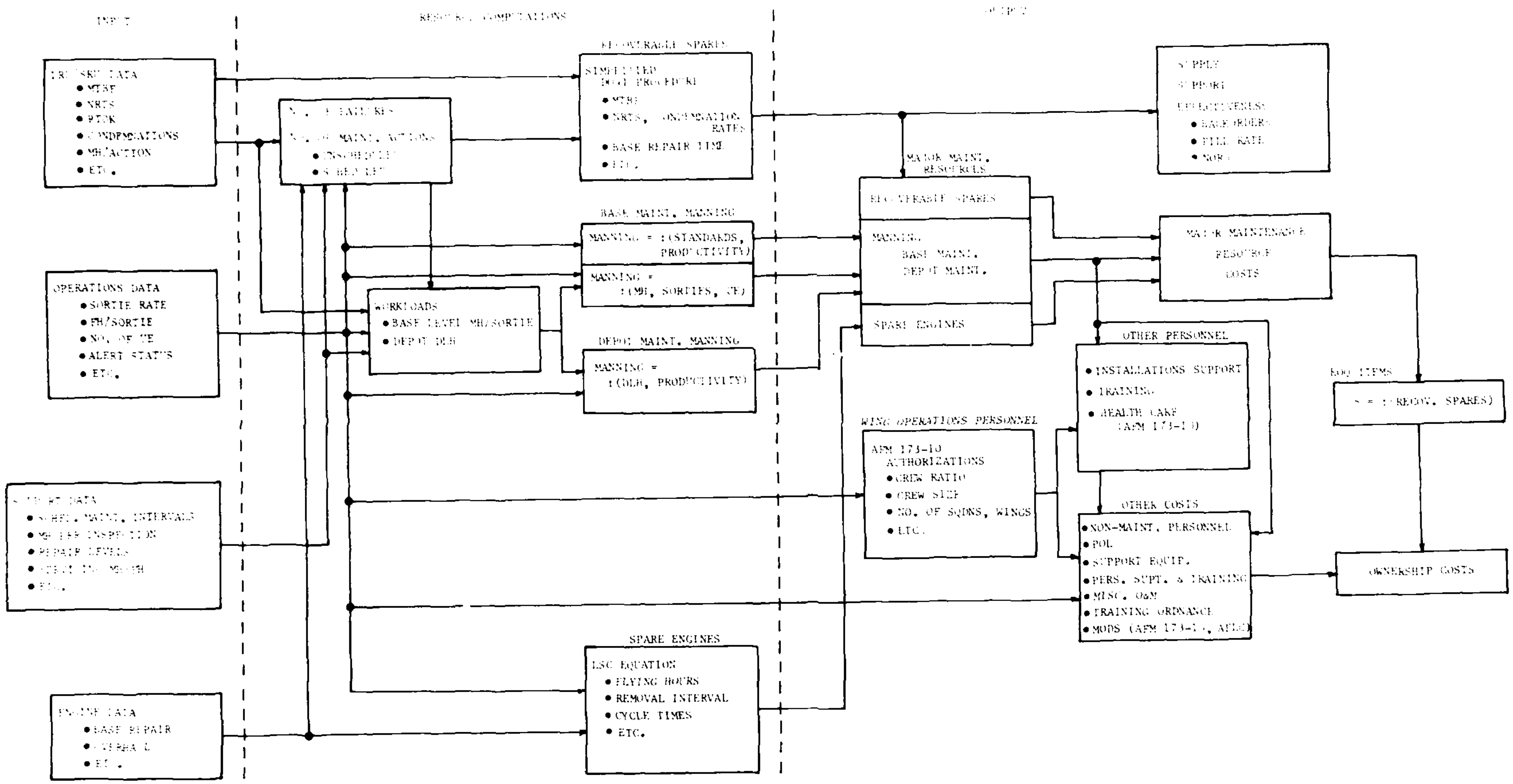

Fig. 1—Information flow for MACO

important outputs. Like budget dollars, these resources are the subject of management attention and estimates for them are important components of many life cycle analysis applications. The output of MACO also includes estimates of both base level and depot level labor hours and the measures of the supply support effectiveness associated with the estimation of recoverable spares. The nondollar outputs of MACO are shown in Table 2.

Table 2

NONDOLLAR OUTPUTS OF MACO

Personnel	Recoverable Spares Quantities
Aircrews	Initial
Command Staff	Replenishment
Security	Spare Engine Quantity
Other Wing Manpower	Supply Support Effectiveness
Base Level Maintenance	Fill Rate
Installation Support	Backorders
Health Care	NORS
Base Level Maintenance Manhours	
Depot Level Direct Labor Hours	

Principal Computational Features—Maintenance Resources and Costs

Algorithms are provided in MACO for each of the cost elements in Table 1 (except the exluded elements). The algorithms are discussed in detail in Secs. III and IV. Many of them are straightforward adaptations of existing BACE/CACE or LSC methods; but most of the maintenance-related algorithms are based on new research and are the most significant computational features of MACO.

For maintenance resources and costs, MACO borrows from the LSC model the important concepts of sensitivity to component reliability and maintainability, and the flow of material through maintenance processes. The MACO algorithms differ from those used in LSC, however, principally because of the desire to generate total resource requirements and full cost, to increase the number of explicit parameters in the model, and to represent more realistically the underlying Air Force processes for determining resource requirements.

The MACO algorithms for Base Maintenance Manpower, Depot Maintenance, and Maintenance Material are discussed briefly below. The MACO algorithms for the maintenance-related cost elements of Spare Engines, Support Equipment, and Replenishment Equipment were adopted directly from existing methods; these and the algorithms for other, nonmaintenance cost elements are covered by the detailed discussion in Sec. IV.

Base Maintenance Manpower. The LSC model deals with base level maintenance manning in terms of direct manhours, and emphasis is given to unscheduled maintenance activities. A primary requirement of MACO was to provide coverage of all significant maintenance activities and to generate estimates of total manpower on which to base dollar costs.

The Air Force establishes maintenance manpower requirements by considering workloads within discrete organizational elements. These elements are termed work centers in maintenance documentation and are identified as responsibility centers/cost centers in the Air Force accounting system. The relationship between workloads and manpower authorizations for individual work centers can deviate considerably from overall averages for maintenance organizations. Manning for some work centers is recognized as being independent of weapon system. For these work centers, the model uses Tactical Air Command (TAC) manpower standards to determine the required manning. Where weapon system characteristics are of significance, the model computes the maintenance workload and converts the workload into required work center manning.

The workload is computed as the sum of manhours for unscheduled maintenance, scheduled inspections, and servicing actions. The workload equations are similar to the maintenance cost equations of the LSC model. A major difference is that the MACO equations compute the total workload of individual work centers.[5] The unscheduled maintenance workload is driven by the number of Unit Equipment (UE)[6] and the flying rates input for each base. LRU input required includes failure rate, Not-Reparable-This-Station (NRTS) rate, retest-OK fraction, and repair-in-place fraction. LRU manhours are needed for several types of actions: preparation/access, in-place repair, remove and replace, bench check, and shop repair. Also, for some maintenance concepts, SRU remove and replace manhours are required. The scheduled workload is computed from input sortie rates (by base, if desired) and inspection intervals expressed in either flying hours or calendar time. Servicing requirements are specified as a servicing manhour per flying hour factor. These various input data elements are input for each work center at each base, and the model computes the corresponding workloads. These workload values are used with input sortie rate and UE data to compute the number of men needed in each work center at each base, which is then multiplied by an average pay and allowance factor to obtain the cost of the work center manpower.

Depot Maintenance. MACO's algorithms for computing depot maintenance cost are similar to those used in the LSC model, but they have been tailored to provide a more direct connection to available depot maintenance cost data and to important cost-driving characteristics of the depot structure. Total depot maintenance cost is computed in MACO as the sum of four major categories of depot maintenance activities: (1) programmed depot maintenance (PDM) of whole aircraft, (2) engine overhaul, (3) repair of exchangeable components, and (4) repair of support equipment. The costs in each category are calculated as the product of the demand rate for repairs, and the labor and material costs per repair. In the LSC model a cost-per-labor-hour rate, which theoretically includes indirect and overhead burdens, is used to cost the direct labor hours calculated for depot maintenance repairs. In MACO the direct labor hours are translated into depot manpower requirements, with indirect and overhead requirements identified separately. This feature of the model permits the estimates to be tied more directly to information contained in depot reporting systems.

Maintenance Material. Four cost elements in MACO—Initial Spares, Replenishment Spares, Base Maintenance Material, and Depot Maintenance Material—fall under this general heading.

Initial and replenishment spares are recoverable items (items of significant value and capable of being repaired to serviceable condition). The LSC approach to recoverable items provides some sensitivity to reliability and maintainability characteristics but lacks explicit

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[5]The MACO equations are based on data for maintenance organizations structured as defined in Air Force Manual 66-1, *Maintenance Management*. Alternative maintenance organizations, such as the Production Oriented Maintenance Organization (POMO), can be approximated through appropriate use of these equations, but further research and data collection would be needed to make equations specifically applicable to such new organizational structures.

[6]The term unit equipment, which was in use when this report was drafted, has been replaced by the term primary aircraft authorization (PAA).

coverage of SRUs and generally does not conform to the methods used by AFLC to acquire and manage these items. To overcome these problems and increase the sensitivity of spare parts estimates to aircraft support policy and support structure variables, MACO uses a set of algorithms derived from the Air Force Recoverable Item Consumption Requirements System (DO41). These algorithms provide an estimate that is generally consistent with the way the Air Force determines spare parts requirements and establishes a budget request. The algorithms also provide a means for determining the supply support effectiveness—e.g., backorders, fill rates, and NORS—that accompany each spares requirement computation.

Inputs used include failure rates, NRTS rates, repair cycle information, flying hours, unit prices, and condemnation rates for each item. MACO maintains a running total of annual spares requirements, netted against spares and available from inventory and repair. These annual requirements provide the means for partitioning the net recoverable item requirements and their costs into the budgetary categories of initial and replenishment spares.

Base and depot maintenance materials are generally consumable items purchased in economic order quantities (EOQ). The LSC model does not provide explicit treatment of these costs, as they are included in an overall material cost for the repair of LRUs. We believe that an aggregate approach is satisfactory for EOQ items as they represent a fairly small proportion of annual aircraft ownership. MACO uses algorithms that compute EOQ cost as a function of recoverable items cost. The algorithms may be used to compute either total EOQ costs or Base EOQ costs alone. MACO provides an alternative procedure for estimating Depot Maintenance Material costs based on depot labor hours and numbers of repairs. The latter procedure may be appropriate where more detailed information is available.

OTHER FEATURES OF THE MODEL

MACO is structured to accept inputs and to generate outputs that reflect time (annual) variations in system characteristics and operating conditions. This allows for the effects of changes in aircraft hardware characteristics as the system matures—for example, LRU/SRU reliability growth—and permits realistic representation of the buildup in aircraft inventory. Both system maturation and the rate of inventory buildup can have significant implications for the demand for ownership resources and funding requirements.

In its present form, MACO provides a complete set of algorithms for estimating ownership costs as a function of individual LRU/SRU characteristics.[7] This fairly fine level of detail is not suitable for all ownership cost analyses, of course, and we have provided an alternative and more aggregated approach for base maintenance manpower cost (see Sec. III) and the depot maintenance algorithms can be used in less detailed fashion. These alternative approaches demonstrate the probable feasibility of developing a model that retains many of the described properties of MACO without the possibly unwarranted burden of LRU/SRU-level inputs.

[7]Working with LRUs and SRUs requires that the user specify the indenture structure—i.e., identify the SRUs that are components of each LRU. LRUs and SRUs are identified in Air Force supply records and depot data systems by individual part numbers. Base level maintenance data use Work Unit Codes to identify components. There is not a one-to-one correspondence between part numbers and Work Unit Codes, so putting together a set of input data from standard Air Force data systems can involve a data processing task that is not at all straightforward.

III. MACO EQUATIONS FOR MAINTENANCE COST ELEMENTS

This section and the next are intended for users of the model or others who are interested in the model equations themselves rather than in the concepts behind the model. The three parts of the model that contain the most extensive improvements over previous models are discussed in considerable detail in this section, including the costs associated with Base Level Maintenance Manpower, Depot Maintenance, and Maintenance Material. Estimating methods adopted from equations in existing models are discussed more briefly in Sec. IV.

BASE LEVEL MAINTENANCE MANPOWER

MACO's scope for base level maintenance manpower covers two LCC elements: Aircraft Maintenance Manpower and Ordnance Maintenance Manpower. These constitute the pay and allowance cost of personnel who perform base level maintenance on aircraft and associated support equipment, training devices, munitions, and components.

Features of Interim Model Approach

Basic Cost Drivers. For base level maintenance labor, improved estimates have conformed to two "facts of life": (1) the maintenance organizational structure is an important determinant of the manpower authorizations for an aircraft system; and (2) the Air Force programming, budgeting, and accounting systems identify projected, current, and past manpower costs with base level organizations, providing at least some useful weapon system cost information. Adoption of the organizational categories that the manpower and budget systems use adds some rigor to the cost estimating process. Among other benefits, it establishes a framework within which a major portion of costs can be traced from an estimate through the programming process to the actual allocation of resources.

Interest in total maintenance manpower cost and quantities led to the computation of cost from pay and allowance rates and the required maintenance manning for the weapon system. This is similar to the approach used in CACE; but MACO differs from CACE in that it estimates the manning internally, with sensitivity to the maintenance requirements of the specific system. Required manning is computed for each work center. For work centers not greatly influenced by weapon characteristics, manning is expressed by equations derived from TAC manpower standards. For each other work center MACO first computes the total maintenance workload. These workload values are then used with input sortie rate and unit equipment (UE) data to compute the number of men needed in each work center at each base, which is then multiplied by an average pay and allowance factor to obtain the cost of the work center manpower.

The link between manhours, which are driven by the characteristics of the individual system, and pay and allowance dollars, which are the budgetary measure of manpower cost, is an essential feature of the interim model's methodology. Useful data for development of this linkage were found in the results of LCOM studies of maintenance manning requirements.

Previous Rand work showed that the manning requirements determined by these studies can be expressed as a function of workload, sortie rate, and number of supported UE aircraft. That work produced a model named MANPOWER for use by OSD(PA&E).[1] The knowledge that a useful methodology could be based on these results was a major reason for using this approach, but it presents other advantages as well. By relating required manning to a sortie rate, the LCOM studies have accounted for one measure of system effectiveness. This allows manning estimating equations based on these data to incorporate effectiveness without additional research. Another advantage of the LCOM study results is that they constitute comparable data in a single format for a number of weapon systems. Gathering and preparing these data for analysis were reasonably straightforward. LCOM results for several weapon systems were available for use in the current study.

An alternative approach would be to develop workload-manning relationships from historical data. Workload information is available from the Maintenance Data Collection System. Manpower authorization data could be obtained from Headquarters USAF. Such an approach was considered for MACO; unfortunately, it has features that made it inappropriate for this study but that could be accommodated in a more extensive study. Authorizations differ from the manning requirements generated by LCOM studies in that they are less strongly driven by the weapon system. As a result, influences that are not of direct concern to the weapon system analyst would unnecessarily complicate the analysis. Also, many USAF units operate more than one mission/design/series (MDS) aircraft. For such units the standard data sources will not provide workload and authorization data for a single weapon system. Additional data or supplementary analysis would be needed to develop suitable data. This was a serious problem for tactical aircraft but may be less critical for some other aircraft types. This approach has problems, but it could be applied to all types of aircraft without the need to rely on LCOM studies. It therefore could be the preferred approach for a future effort to develop models useful for all USAF aircraft.

The LCOM data has several limitations that bear on its usefulness for our purposes. Limitations partially overcome in developing MACO involve inconsistent work center coverage, characteristics of the operating command, and maintenance organizational structure. Although we have used the LCOM studies as a single data base, they were separate studies with specific objectives and considerations that were not all the same for all aircraft. Each study is therefore somewhat different from the others. Of particular importance to this research is that of differences in the work centers covered, which had several implications for the use of the data. For example, studies are available for only two aircraft with integrated avionics, the F-111D and F-16. It was therefore necessary to combine data for some of the integrated avionics work centers so as to have sufficent data for analysis. Also, a body of compatible LCOM studies is available only for aircraft operated by TAC. Other commands have not (at least not yet) adopted the use of LCOM as an approved means of determining manning requirements. MACO is applicable to tactical aircraft operated by PACAF or USAFE to the extent that the aircraft and their operations are similar to those of TAC. LCOM gives separate consideration to distinct parts of the maintenance workload associated with individual work centers—individual elements of the maintenance organization. LCOM studies to date have all used the organizational structure defined by AFM 66-1.[2] Structures such as those used in the Production Oriented

[1] W. S. Furry, K. M. Bloomberg, J. Y. Lu, C. D. Roach, and J. F. Schank, *MANPOWER: A Model of Tactical Aircraft Maintenance Personnel Requirements*, Vol. I, *Overview of Model Development and Application*, R-2358/1-PA&E, and Vol. II, *Technical Appendixes*, R-2358/2-PA&E, April 1979.

[2] *Maintenance Management*, Vol. I, *Policy*, Department of the Air Force, AFM 66-1, 1 May 1974.

Maintenance Organization (POMO) and the Centralized Intermediate Logistics Concept (CILC) are handled by the MACO in an approximate way as a result of appropriate manipulation of the LCOM data, but precise representation of these alternative structures is not feasible.

The use of LCOM study results as the basis for a manhour-manning relationship determines the types of manhours used in MACO. LCOM studies attempt to capture the manhours for all types of maintenance actions that affect the ability to generate sorties. MACO therefore addresses not only unscheduled maintenance (the only maintenance activity considered by some maintenance cost models), but significant inspections and servicing actions as well. Input to MACO must account for all scheduled and special inspections that generate significant workload and for all servicing actions involved in preparing aircraft for or recovering from a sortie.

During development of MANPOWER it was found that linear equations of the form $Y = A + B(X1) + C(X2) + D(X3)$ were statistically significant, where Y = manning requirement, X1 = maintenance manhours per sortie, X2 = sortie rate, X3 = UE, and A, B, C, and D are parameters determined through regression analysis. Better results were obtained, however, with logarithmic-linear equations of the form $\ln Y = A + B(\ln X1) + C(\ln X2) + D(\ln X3)$. Logarithmic-linear equations are used in MACO, except for one work center for which the coefficients have unrealistic signs. For this work center, an acceptable linear equation was developed for use in the model.

The equations for MACO differ from those of the earlier work in that they apply to a different level of the maintenance organization. The MANPOWER model was developed for use during concept formulation, when the data available are limited. To accommodate the limited data, the MANPOWER equations were developed to estimate manning requirements for four work center groups. The hardware and maintenance concept sensitivity sought for MACO requires more detailed information. Our approach has been to use a separate equation for each work center unless some specific criterion, such as statistical significance, clearly shows that a single equation applies to more than one work center.

Because the model is to represent the links between workload and manning for individual work centers, the development of the model specifically considered various aspects of operating policies, deployment plans, mission effects, and alternative maintenance concepts. These are described below, along with the need for both detailed and aggregate estimates.

Operating Policies and Deployment Plans. A major operational consideration is that, although aircraft maintenance cost is generally estimated for a period of peacetime operations, the maintenance organization must have enough manpower to function successfully in a wartime environment. Either the peacetime or the wartime manning requirement may be the greater for a specific work center, because aircraft activity rate and personnel availability are both greater in a combat environment.

Increased flying leads to an increase in the requirement for maintenance manhours, which may be either larger or smaller than the increase in available manhours. MACO, like the LCOM studies it is partly based on, assumes that combat damage is repaired by personnel from outside the unit or that combat-damaged aircraft are replaced. It follows that the maintenance actions performed by the basic maintenance organization in wartime are the same types of actions as are needed in peacetime. Although the types are the same, there are more of each type because of the increased flying activity. The wartime maintenance workload can therefore be derived from the wartime activity rate and peacetime reliability and maintainability data.

Personnel availability is not so easily addressed. It is different for each workweek that the Air Force uses. Table 3 shows that a man is expected to be available for duty 242 hours per month in a wartime environment, and that number ranges from 144 to 183 for various locations in peacetime. MACO computes both wartime and peacetime requirements. Some standard-manned work centers have different standards for these two conditions, and both are used in the model. For others, the wartime and peacetime requirements are assumed to be the same, and the single available standard is used for both requirements. LCOM simulations have been run only for wartime scenarios, but peacetime requirements for LCOM work centers can be computed from the formula:

$$(\text{Peacetime workload/Wartime workload}) \times (\text{Wartime manning}) \times (\text{Wartime availability/Peacetime availability})$$

The two workloads are determined from the MACO manhour equations, based on peacetime and wartime sortie rates. The wartime personnel availability is taken as the usual 242 man-hours per man per month for this calculation, and the peacetime availability is an input that should usually be one of the values shown in Table 3.

The manpower estimates from MACO differ from those of the MANPOWER model in the method of accounting for personnel availability. The MANPOWER equations estimate direct labor authorizations; i.e., the total number of direct personnel (not classified as supervision or overhead) required in the organization to insure that a sufficient number will always be available to staff each shift at the required level. The typical 242 hour availability is implicit

Table 3

AVAILABLE MANHOURS PER MAN

Condition	Location	Work Week (Hours)	Available Hours per Man-month[a]
Normal	CONUS, Europe, Alaska	40	144
Extended Normal	Philippines, Taiwan	48	181
Extended Remote (Dependents not authorized)	Remote sites	48	183
Emergency	Wartime Capability Forces	60	242

SOURCE: Lt. Roy E. Smoker, Military Manpower Availability Study, Hq USAF, Directorate of Manpower and Organization, Manpower Resources and Analysis Group, Report No. 73-4, October 1973, p. 7.

[a]Typical values--actuals vary from year to year with changes in authorized categories of unavailable time.

in the methodology. The regression equations in MACO compute the manning required to staff two 12-hour shifts per day, seven days per week, assuming each individual is available the full 84 hours per week. This is the shift policy used in the simulation runs in most of the LCOM studies. The final LCOM results are greater than the simulated manning by an amount large enough to compensate for the lower personnel availability under a standard 60 hour wartime workweek. MACO addresses this additional direct requirement in a separate calculation, allowing for separate treatment of personnel availability; the user can specify an atypical workweek if he so chooses.

The workweek is not the only factor that varies with geographical location. Different locations are likely to have different operating practices that may result in different maintenance requirements. The threat an aircraft faces will vary with location. Units in Europe maintain an alert force, but CONUS units do not need one. MACO allows the user to specify the number of alert aircraft in a squadron. The model then associates one manpower authorization with each alert aircraft. The threat also influences the mix of sortie types flown. MACO does not allow the user to specify the sorties to be considered; rather, a sortie mix typical of combat-coded fighter-attack aircraft is built into the LCOM results from which part of the methodology is derived. The model does accept input to account for other operating differences that can vary with location. Repair times, for example, include some travel time to and from the aircraft and will depend on how the aircraft are situated. Assigning parked aircraft to individual sites distributed over a wide area would call for more travel time than if the aircraft were all at a single site and can be reflected in the repair times input to the model, although the model does not estimate such effects directly.

Units operating in different parts of the world are likely to be under different major commands. Each command is likely to have some unique manpower standards for some work centers. The scope of this study did not allow this effect to be investigated in enough detail to permit its incorporation into MACO. The manpower standards of the Tactical Air Command are the basis for the model's estimate for those work centers to which the standards apply.

The number of operating sites to which a given number of units deploys has a significant effect on the total manpower required by those units. The manpower requirement increases with the number of deployment sites. Most maintenance activities must be carried out at each site, regardless of the number of aircraft there. There is thus a minimum amount of manpower at each site. Even for work centers driven strongly by the number of supported aircraft or their activity rate, the workload is not strictly proportional to that number or activity rate.

Operational requirements are among the factors that give rise to minimum manning levels for various work centers. If a work center will be called upon to perform some specific task during a particular shift, then that work center must be staffed for that shift with at least the number of personnel that are needed to carry out that task. This establishes a minimum manning level independent of workload. Examining the LCOM data base reveals that three men or more are almost always required. In MACO, if a low workload results in a computed shift manning requirement less than three, this estimate is discarded and the value three is used instead. The model is based on a wing consisting of one to three squadrons that may be deployed in wartime to one to three operating sites. The user specifies the number of units and the deployment pattern for use in each run.

Mission Effects. It has not been feasible to construct MACO with sensitivity to all mission effects. As noted above, different types of sorties cannot be modeled individually. The model does, however, address a specific alternative to the basic fighter/attack mission: reconnaissance. The model uses separate estimating equations for some work centers for reconnaissance aircraft. Separate standards for several standard-manned work centers are incorporated into the model. Also, as shown in Tables 4-6, the LCOM results for three work centers contain significantly different data for reconnaissance aircraft than for other types. For the navigation and inertial navigation work centers, the reconnaissance aircraft has a greater workload than nonreconnaissance aircraft but about the same manning. For the photographic-sensors work center, the reconnaissance workload is very much greater than that of other aircraft, and the difference is reflected in greater manning. The photographic-sensor workload for the RF-4C is about 20 times as large as the corresponding workload for a similar number of F-4Es. The estimating equations for these work centers were derived so as to distinguish between reconnaissance and other aircraft.

Combat crew training (CCT) imposes somewhat different maintenance requirements than do operational missions. The sortie profile is different, making available LCOM results inapplicable to CCT squadrons. Also, some manpower standards are different. These unique features of CCT are not accounted for in MACO. The aircraft used in CCT are a large enough portion of a typical tactical aircraft fleet to make this a significant limitation of the model. If this model is extended in the future, a CCT methodology should be one of the features added.

Alternative Maintenance Concepts. In MACO, greater flexibility is available for handling alternative maintenance concepts than exists in most cost models. This model has, along with most others, the ability to accept NRTS rates and repair times that reflect maintenance capability associated with different ways of conducting maintenance. This sensitivity is only

Table 4

LCOM DATA FOR NAVIGATION WORK CENTER

Weapon system	Simulated manning	Manhours per sortie	Sortie rate	Unit equipment
A-7D	4	0.86	0.87	24.
A-7D	5	0.77	0.87	48.
A-7D	8	0.81	0.87	72.
A-10	3	0.11	0.90	24.
A-10	3	0.13	0.93	48.
F-4E	4	0.64	0.90	18.
F-4E	4	0.62	0.98	24.
F-4E	4	0.63	1.01	36.
F-4E	6	0.62	1.11	48.
F-4E	8	0.6	1.06	72.
RF-4C	3	1.67	0.67	18.
RF-4C	5	1.56	0.67	36.
RF-4C	7	1.62	0.67	54.

SOURCE: Management Engineering System Analysis Team, Office of the Directorate of Manpower and Organization (XPM), Headquarters, Tactical Air Command, Langley Air Force Base, Virginia.

Table 5

LCOM DATA FOR INERTIAL NAVIGATION WORK CENTER

Weapon system	Simulated manning	Manhours per sortie	Sortie rate	Unit equipment
A-7D	5	1.16	0.87	24.
A-7D	8	1.27	0.87	48.
A-7D	12	1.4	0.87	72.
F-4E	4	1.16	0.90	18.
F-4E	4	1.2	0.98	24.
F-4E	8	1.16	1.01	36.
F-4E	9	1.17	1.11	48.
F-4E	16	1.18	1.06	72.
RF-4C	6	3.31	0.67	18.
RF-4C	9	3.23	0.67	36.
RF-4C	13	3.11	0.67	54.

SOURCE: Management Engineering System Analysis Team, Office of the Directorate of Manpower and Organization (XPM), Headquarters, Tactical Air Command, Langley Air Force Base, Virginia.

Table 6

LCOM DATA FOR PHOTOGRAPHIC-SENSORS WORK CENTER

Weapon system	Simulated manning	Manhours per sortie	Sortie rate	Unit equipment
A-7D	3	0.53	0.87	24.
A-7D	4	0.52	0.87	48.
A-7D	5	0.53	0.87	72.
A-10	4	0.23	0.90	24.
A-10	4	0.22	0.93	48.
F-4E	4	0.43	0.90	18.
F-4E	4	0.43	0.98	24.
F-4E	4	0.46	1.01	36.
F-4E	4	0.45	1.11	48.
F-4E	6	0.44	1.06	72.
RF-4C	20	9.82	0.67	18.
RF-4C	26	9.39	0.67	36.
RF-4C	38	8.95	0.67	54.

SOURCE: Management Engineering System Analysis Team, Office of the Directorate of Manpower and Organization (XPM), Headquarters, Tactical Air Command, Langley Air Force Base, Virginia.

indirect and is by itself insufficient. MACO directly estimates certain effects of a limited range of maintenance concepts.

This model can estimate requirements for two concepts of the maintenance organization. In one case the standard Air Force organizational structure is used, with some work centers doing both on-aircraft and off-aircraft work. Typically, maintenance specialists assigned to these work centers are detailed for on-aircraft work as the need for their skills arises. The model can also address the situation in which different centers do on- and off-aircraft work. In that case no single center works both on the aircraft and in the shop. This split between on- and off-aircraft work has been used for some time for integrated avionics maintenance and is one of the features of some alternative maintenance concepts now being tested for USAF tactical aircraft, including POMO and CILC.

In practice, POMO and CILC have other features that are not represented in the model. Component removal rates may be different than for the conventional organizational structures, because of the different skills available on the flight line. Task times may also be different because of different times required for travel to and from the aircraft. Consolidating on-aircraft personnel and cross-training them can reduce the number of personnel required to support a given sortie rate. Sensitivity to such effects could not be built into MACO because of a lack of information as to the exact nature and magnitude of the changes. Future work should provide the basis for greater maintenance concept sensitivity in a future model.

The separation of on- and off-aircraft work was also used in the development of estimating equations for flightline avionics manpower for organizations supporting integrated avionics systems. In effect that associates an intermediate maintenance concept with integrated avionics, using the standard organization for organizational and field maintenance and separating on- and off-aircraft work for avionics maintenance.

Aggregate Estimates. MACO has been built to use hardware data detailed enough for the model to show the effect of component (SRU) design changes upon weapon system O&S cost, which is necessary if LCC is to be a criterion in design trade studies. There are, however, many situations in which it is desirable to estimate O&S cost without such detail. Cost estimates are often needed early in the development of a system, before the details of a design have been developed. Many decisions at upper management levels do not specifically address hardware details. To support such decisions, it is often best to use a less complex model that retains the essential features of the problem but omits unnecessary detail. Naturally, estimates developed at an aggregate level should be compatible with more detailed estimates, making it easier to reconcile estimates from different stages in development or at different management levels.

MACO achieves this compatibility by combining manhour data at the subsystem (2-digit work unit code) level with a set of factors that distribute unscheduled maintenance manhours to the various work centers. Tables 7 and 8 present factors derived from Maintenance Data Collection System data for the F-4E and F-15, respectively representing systems with conventional and integrated avionics. Each model user should develop such factors from historical data on aircraft similar to the one he is costing.

Development Of Methodology

The cost of base maintenance manpower in year y is computed as

$$CBLMM_y = MTA_y APA + OPA \sum_{b=1}^{NB} OFCRM_{y,b}$$

where

$$OFCRM_{y,b} = \sum_{u=1}^{NU_b} UOFCRM_{y,b,u}$$

$$MTA_y = \sum_{b=1}^{NB} \left(OHSM_{y,b} + \sum_{w=1}^{NWC} WCM_{y,b,w} \right)$$

$$OHSM_{y,b} = \sum_{u=1}^{NU_b} UOHSM_{y,b,u}$$

$$WCM_{y,b,w} = \sum_{u=1}^{NU_b} WCMNG_{y,b,w,u}$$

$UOFCRM_{y,b,u}$ and $UOHSM_{y,b,u}$ are the officer manpower and overhead and supervision manpower, respectively, for unit u deploying from base b. NB is the number of bases, and NU_b is the number of units at base b. $WCMNG_{y,b,w,u}$ is the direct maintenance manpower needed at base b in work center w because of the work center's support of unit u. The summations over u produce the total manning by work center at base b in year y. OPA and APA are the officer and airman pay and allowance rates.

Distinctly different methodologies are used to estimate the direct manpower for the standard manned and LCOM manned work centers. We apply the term "standard manned" to all work centers having requirements derived by means other than LCOM. In a few cases, in which standards either do not exist or use parameters not readily available for cost estimation, simple estimating equations have been derived from actual authorization data. The equations for the standard manned work centers are discussed only briefly herein, because they were documented as part of the MANPOWER model, for which they were originally developed. This discussion is followed by a more detailed explanation of the derivation of the equations for the LCOM manned work centers.

Manpower Standards. For the standard manned work centers, MACO borrows heavily from the MANPOWER model. The relevant standards were converted into convenient manpower estimating equations for use in the earlier model, and the same equations are used here for the standard organizational structure. They produce estimates of manpower authorizations for the areas listed below.

Chief of Maintenance
Alert Force
Machine Shop

Table 7

DISTRIBUTION OF F-4E MANHOURS TO WORK CENTERS

Work Center	11	12	13	14	22	23	24	41	42	44	45	46	47	49	51	52
Flight Line	5	3	15	2	0	0	0	0	6	13	1	2	1	1	0	0
Inspection	16	10	2	4	0	1	0	1	1	1	6	2	3	5	0	0
Structural Repair	65	18	13	30	100	5	0	1	2	8	1	1	2	14	2	0
Jet Engine	0	0	0	0	0	81	0	8	5	0	0	0	0	0	0	0
Repair & Reclamation	4	23	26	23	0	2	0	0	0	0	0	0	0	0	0	0
Fuel	7	0	0	0	0	0	0	0	0	0	0	89	0	0	0	0
Electrical	1	3	9	6	0	7	0	0	65	71	1	2	0	81	1	0
Pneudraulic	1	7	33	33	0	0	0	0	0	0	89	1	0	0	0	0
Environmental	0	11	0	0	0	0	0	77	0	0	0	0	95	0	0	0
Egress	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Communications	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
Navigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
ECM	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Inertial Navigation	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Automatic Flight Control	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	99
Instrumentation	0	3	0	1	0	4	0	10	2	6	2	3	0	0	95	0
Weapons Control	0	0	0	0	0	0	0	2	10	0	0	0	0	0	0	0
Photographic	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
LCOM MH per 1000 sorties	1998	332	731	1001	3	1153	--	277	247	131	321	852	167	45	347	327

Table 7—continued

Work Center	55	57	63	65	71	72	73	74	75	76	77	91	92	93	96	97
Flight Line	0	0	0	0	0	0	0	0	2	0	0	0	0	11	0	0
Inspection	0	0	0	0	0	0	0	0	3	0	0	0	0	17	8	0
Structural Repair	0	0	0	0	0	0	0	0	74	1	2	28	3	47	0	1
Jet Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Repair & Reclamation	0	0	0	0	0	0	0	0	0	0	0	0	24	19	0	0
Fuel	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Electrical	0	0	0	0	0	0	0	0	0	0	0	0	69	0	0	0
Pneudraulic	0	0	0	0	0	0	0	0	5	0	0	0	0	4	0	0
Environmental	0	0	0	0	0	0	0	0	0	0	0	5	0	0	17	0
Egress	0	0	0	0	0	0	0	0	0	0	0	67	3	0	55	100
Communications	0	0	0	0	34	0	0	0	0	0	0	0	0	0	19	0
Navigation	0	0	0	0	21	99	0	0	0	0	0	0	0	0	0	0
ECM	0	0	0	0	0	0	0	0	0	98	0	0	0	0	0	0
Inertial Navigation	0	0	0	0	41	0	27	0	0	0	0	0	0	0	0	0
Automatic Flight Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Instrumentation	100	0	0	0	0	0	24	0	0	0	0	0	0	0	2	0
Weapons Control	0	0	0	0	4	0	49	100	17	1	1	0	0	0	0	0
Photographic	0	0	0	0	0	0	0	0	0	0	96	0	0	3	0	0
LCOM MH per 1000 sorties	9	--	--	--	3758	257	902	3114	120	601	113	5	4	20	3	7

Note: Percentages may not total 100 due to rounding.

Table 8

Distribution of F-15 Manhours to Work Centers

Work Center	11	12	13	14	22	23	24	41	42	44	45	46	47	49	51	52
Flightline	3	3	9	1	0	1	1	1	0	6	0	1	5	3	0	0
Inspection	8	5	1	3	0	1	1	3	0	1	1	0	0	2	0	0
Structural Repair	65	15	2	37	100	6	1	4	0	2	2	1	1	21	2	0
Jet Engine	0	0	0	0	0	88	81	0	0	0	0	0	0	0	0	0
Repair & Reclamation	4	22	13	23	0	0	0	0	0	0	0	0	0	0	0	0
Fuel	7	0	0	0	0	0	0	0	0	0	0	83	0	0	0	0
Electrical	0	4	8	2	0	1	1	1	39	70	0	3	0	42	0	0
Pneudraulic	2	8	64	23	0	0	14	1	4	0	86	0	0	0	0	0
Environmental	0	3	0	0	0	0	0	81	1	0	0	0	70	29	0	0
Egress	0	33	0	0	0	0	0	0	1	0	0	0	0	0	0	0
AFC/Instruments	2	0	0	3	0	2	0	0	1	2	10	7	7	0	22	21
Weapons Control/ Inertial Nav.	0	3	0	0	0	0	1	1	1	0	0	0	0	0	0	0
COM/NAV/PEN Aids	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Avionics AGE	0	0	0	2	0	0	0	1	13	1	0	1	2	2	1	1
Manual Test Stations	0	5	1	5	0	1	0	0	40	17	0	4	9	1	3	1
Automatic Test Stations	7	0	1	0	0	0	0	7	0	1	0	0	0	0	71	77
LCOM MH per 1000 sorties	2269	433	1268	788	25	2250	396	237	413	263	457	612	65	35	361	330

Table 8—continued

Work Center	55	57	63	65	71	72	73	74	75	76	77	91	92	93	96	97
Flightline	0	0	0	0	0	0	0	0	0	1	0	25	0	0	0	5
Inspection	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Structural Repair	1	0	0	0	0	0	0	0	39	1	0	28	0	0	0	0
Jet Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Repair & Reclamation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fuel	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Electrical	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Pneudraulic	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Environmental	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Egress	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	95
AFC/Instruments	20	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Weapons Control/ Inertial Nav.	0	17	0	0	9	0	0	12	0	2	0	0	0	0	0	0
COM/NAV/PEN Aids	0	0	14	8	4	0	0	0	0	85	0	0	0	100	0	0
Avionics AGE	14	6	11	15	5	0	0	4	0	0	0	0	0	0	0	0
Manual Test Stations	28	0	74	63	22	0	0	26	0	0	0	5	0	0	0	0
Automatic Test Stations	35	77	0	13	59	0	0	57	56	9	0	0	0	0	0	0
LCOM MH per 1000 sorties	99	134	1044	910	1181	--	--	5858	216	187	--	7	--	5	--	3

Note: Percentages may not total 100 due to rounding.

Metal Processing
Corrosion Control
Survival Equipment
Nondestructive Inspection
Aerospace Ground Equipment
Precision Measurement Equipment Laboratory
Munitions Maintenance
Overhead and Supervision
Officers

Some of these work centers are split under alternative maintenance organizations such as are used with POMO and CILC. Appropriate modifications have been made to the MANPOWER equations to account for this situation. The equations compute manning as workload divided by personnel availability. Requirements that stem from maintenance problems peculiar to one weapon system are not accounted for. Some F-111 authorizations, for example, are higher than the standards would provide. The additional manpower is due to extraordinary problems that are not typical of tactical aircraft. Such unique requirements are not included in the model.

The Chief of Maintenance organization is responsible for the management of all wing maintenance activity. Equations that generate peacetime requirements for the nine functions that compose Chief of Maintenance are shown in Table 9. They express workload in terms of unit equipment (including both mission and base support aircraft), flying hours, and sorties. Each functional area has a maximum and minimum number of authorizations, depending on personnel availability. The table gives these limits for three availability levels. The equations are applied to individual deploying units, using the total number of UE in the unit (including base support aircraft) and the total number of flying hours and sorties flown by the unit.

For most Chief of Maintenance functions, alternative contingency standards establish the manning for wartime operations. These contingency requirements are published in a separate document. The critical requirement for each function is the greater of the peacetime and wartime requirements.

In MACO, the Alert Force manning requirement for a unit includes one man for each alert aircraft. The number of aircraft on alert status is specified by the user. This manning level is considered appropriate according to information supplied by TAC headquarters.

The Machine Shop typically has a very light workload. As a result, this work center normally operates with minimum manning. Through observation of the manning requirements of existing aircraft, it was found reasonable to assume five men for each unit of combat aircraft and three men for each unit of reconnaissance aircraft.

The Metal Processing work center typically has a minimum manning level resulting from a low workload. The situation is much the same as for the Machine Shop. In this case the appropriate number of men per unit was found to be three for combat aircraft and two for reconnaissance units.

There is no manning standard for Corrosion Control. A regression equation derived from actual authorizations for the F-4, F-15, F-16, F-105, F-111, and A-7 aircraft was found to be a suitable estimating equation. This gives authorizations as:

$$\text{WCMNG} = 0.92 + 0.14(\text{UE})$$

The statistics for this equation are:

Coefficient of determination (R^2) = 0.65
Standard Error of Estimate (SEE) = 2.34
Mean Absolute Relative Deviation (DEV) = 30%.

This overall equation and the UE coefficient are both significant at the 99 percent level.

TAC has separate wartime and peacetime standards for Survival Equipment. These vary by aircraft type, because the manning requirement is affected by mission and crew size. The peacetime standard ties manning to UE or a combination of UE and sortie rate, depending on aircraft. The wartime standard relates authorizations to a unit's deployed location and number of aircraft. The variation in authorizations of actual units is not great enough to justify building the complexities of the standards into the model. A satisfactory estimating equation was

Table 9

PEACETIME CHIEF OF MAINTENANCE EQUATIONS

Functional Area	Workload Equation[a]	Manpower Limits[b] 144	180	242
Chief of Maintenance[c]	2125.6 + 0.5032(FH)	18-26	14-21	11-16
Quality Control	3477.2 + 0.7469(S)	26-33	21-26	16-20
Maintenance Control	475.397	4	4	4
Job Control	1082.7 + 1.143(FH)	16-33	13-27	9-21
Plans and Scheduling	532.8 + 1.0813(S)	6-17	5-15	4-12
Documentation	264.2 + 6.393(UE)	2-8	2-7	2-5
Materiel Control	$19.18(S)^{0.4269}$	1-4	1-4	1-3
Maintenance Supply Liaison	505.8 + 1.013(S)	6-17	5-15	3-11
Production Control	713.7 + 0.9658(S)	7-16	6-15	5-12

[a]S = (SR)(Flying days/month); FH = (S)(Sortie length).

[b]Limits are shown for personnel availabilities of 144, 180, and 242 hours per month.

[c]The core of the Chief of Maintenance organization, including the Deputy Commander for Maintenance, and the functions of Administration, Production Analysis, and Training Management.

obtained through regression analysis of 34 data points for the F-4, F-15, F-16, F-105, F-111, and A-7 aircraft. This equation is

$$WCMNG = 3.02 + 0.12(UE)$$

Its statistics are:

$$R^2 = 0.74$$
$$SEE = 1.63$$
$$DEV = 15\%.$$

This equation and the UE coefficient are both significant at the 99 percent level.

The standard for Nondestructive Inspection (NDI) manning requires knowledge of the relative frequencies of several different types of inspections that this work center would perform. Because this information is not likely to be available for the generation of a typical cost estimate, we sought an alternative. Analysis of authorizations for 31 units operating F-4, F-15, F-16, F-105, F-111, and A-7 aircraft produced the following regression equation.

$$WCMNG = 0.89 + 0.14(UE)$$

The equation's statistics are:

$$R^2 = 0.66$$
$$SEE = 2.35$$
$$DEV = 25\%.$$

This equation and the UE coefficient are both significant at the 99 percent level. The standard specifies a minimum wartime manning of seven, so the regression equation was modified to produce seven authorizations for an 18 UE squadron:

$$WCMNG = 4.48 + 0.14(UE)$$

There are three separate work centers responsible for the maintenance of powered Aerospace Ground Equipment (AGE). Management of AGE maintenance is handled by one work center. A second work center performs repair and inspection work. The third is responsible for servicing the AGE and for pickup and delivery of items of AGE moved to or from the shop area. Both peacetime and wartime standards exist for these work centers, but the peacetime requirement is based on the number of pieces of powered AGE supported—a quantity that may not always be available to model users. The wartime standards relate manning to sorties, which is a more appropriate variable, and typically produce a greater requirement than the peacetime standards. For these reasons, the model uses the wartime standards as the basis for the computed requirement for AGE maintenance, applying the wartime or peacetime sortie rate depending on which manning is being computed.

AGE manning is computed separately for management and the operating work centers. The AGE Management standard gives manning directly for various numbers of UE. It is presented in Table 10. For combat aircraft, the standards specify workloads for the operating work centers as functions of the average number of monthly wartime sorties. Converting these into manning requirements gives:

AGE Work Center	Avionics	Manning Equation
Repair/Inspection	Conventional	3.49(S)/PA
"	Integrated	6.20(S)/PA
Service/Pickup/Delivery	Conventional	4.44(S)/PA
"	Integrated	7.90(S)/PA

Here S is the number of monthly sorties and PA is the wartime personnel availability in manhours per manmonth. The operating work center manning for reconnaissance aircraft is specified directly as shown in Table 11 for squadron sizes up to 24 UE.

The manning standard for Precision Measurement Equipment Laboratory (PMEL), like that for the AGE work centers, uses a variable that is inappropriate for our purposes. In this case it is the number of PME items supported. An examination of actual authorizations for 16 bases revealed that using a constant manning for PMEL is as acceptable as more complex procedures. For 75 percent of the cases examined, 23 men per PMEL shop is within 25 percent of the actual authorization and that figure is used in the model.

Munitions Maintenance consists of a number of work centers that are charged with managing and performing maintenance on missiles and munitions and on aircraft gun and weapons release systems. TAC has started to examine munitions manning in LCOM studies; but at present this manning is specified by manpower standards, and MACO is based on the existing standards.

Each work center or functional area has just one standard that provides for both peacetime and wartime requirements. In most cases, this is a peacetime standard based on 144 hours/month personnel availability that gives enough manpower to cover a wartime operation with 242 hours/month availability. Peacetime standards specify a constant manning level for the following functions.

Commander
Maintenance Supervision
Training
Technical Administration
Standardization
Munitions Services

A total of 17 personnel are authorized for these functions for each wing, regardless of wing size or activity rate.

Other peacetime standards involve a workload expressed as a function of the numbers of personnel required in various categories. These standards are:

Function	Manning Standard
Mobility	Manhours = 133.1 - 0.11(P1) + 0.0008048(P1)
Administration	Manhours = 2.01(P2)0.9889
Maintenance & Storage	Manhours = P3/(0.06646 + 0.001186(P3))

Table 10

WARTIME MANNING FOR AGE MANAGEMENT

Number of UE	Manning
3	2
6	2
9	3
12	3
15	3
18	4
24	4
28	4
33	5
36	5
48	5
56	6
72	6
84	7
90	7
96	8

SOURCE: Derived from data obtained from the Office of the Directorate of Manpower and Organization (XPM), Headquarters, Tactical Air Command, Langley Air Force Base, Virginia.

Table 11

AGE WARTIME MANNING FOR RECONNAISSANCE AIRCRAFT

Number of UE	Manning
3	8
6	8
9	12
18	16
24	20

SOURCE: Derived from data obtained from the Office of the Directorate of Manpower and Organization (XPM), Headquarters, Tactical Air Command, Langley Air Force Base, Virginia.

In these equations, P1 is the number of personnel on mobility status, approximated in MACO by the number of personnel in all other munitions work centers except Administration. P2 is the number of military personnel authorized for all of munitions maintenance, approximated here as all other munitions work centers except Mobility. P3 is the number of authorizations for Missile Maintenance, Munitions Maintenance, Storage and Handling, Equipment Maintenance, and Inspection. The work centers omitted from P1 and P2 are left out only to simplify the computations. If they were left in, then the manning requirements for Mobility and Administration would be interrelated. This is avoided by leaving each of these work centers out of the total manning used to compute the requirement for the other. The manning for these functions is small enough that the integer numbers of men resulting from this approximation will usually be the same as if the actual total munitions manning were used.

The Air Force uses wartime standards to establish peacetime as well as wartime requirements for some work centers. The standard for Weapons Loading is

$$WCMNG = 4SQ + 2UE$$

where SQ is the number of squadrons of aircraft to be supported at a single site. Other wartime standards are of the form

$$WCMNG = SR(UE)[A + B(KAS) + C(1 - KAS)]$$

where SR is the sortie rate and KAS is the fraction of sorties that are air superiority missions. Values of the parameters A, B, and C are given in a separate classified document. The work centers involved are:

Weapons Release	Munitions Maintenance
Gun Services	Storage and Handling
Missile Maintenance	

There are four work centers for which the standards use parameters not likely to be known to a cost estimator. The standards for Munitions Supply Accountability and Munitions Control are based on the number of work orders processed. An estimating equation was developed as an alternative to the standards by analyzing authorization data for 27 units flying F-4, F-15, F-111, A-7, and A-10 aircraft. The equation relates the combined authorizations for these work centers to the number of personnel in Missile Maintenance, Munitions Maintenance, and Storage and Handling and to a dummy variable that indicates whether the unit has an air superiority mission. This variable is needed because air-to-air missiles require more personnel than other munitions. The equation is

$$WCMNG = 6.25 + 0.06(P4) + 2.38(AS) .$$

Here P4 is the number of personnel in the Missile Maintenance, Munitions Maintenance, and Storage and Handling work centers and AS is 0 (if the unit has an air superiority mission) or 1 (if there is no air superiority mission). The air superiority variable adjusts the computed manning to offset the upward bias associated with the extra maintenance personnel and storage and handling personnel required in units that have air-to-air missiles. The statistics for this equation are:

$$R^2 = 0.67$$

$$SEE = 1.71$$

$$DEV = 8\%.$$

The Equipment Maintenance and Inspection work centers have standards based on the number of munitions trailers and the number of munitions line items stocked. These parameters, like the number of work orders, are not likely to be available to the user of MACO. An alternative was therefore developed from authorization data. The combined manning of these work centers can be expressed as

$$WCMNG = 0.12057(P4)$$

with P4 defined as above. The relevant statistics are:

$$R^2 = 0.98$$

$$SEE = 2.32$$

$$DEV = 15\%.$$

These results for Munitions Maintenance are for aircraft with fighter or attack missions. TAC also has reconnaissance aircraft that carry munitions that are different from those of other aircraft and have different personnel requirements. There is no complete set of standards for reconnaissance aircraft. The interim model borrows the MANPOWER procedure of assigning two men per aircraft.

Overhead and supervision requirements for the LCOM shops are specified in a TAC manning guide. These requirements are nearly the same for all aircraft and are shown by maintenance squadron in Table 12, for several sizes of deploying unit. The only difference is between conventional and integrated avionics, and this is never more than one man. The values shown for 90 and 96 UE were developed by extrapolation from the data for smaller unit sizes.

The number of officers associated with maintenance activities is given by several standards. These authorizations vary with UE, flying hours, and various munitions workload

Table 12

OVERHEAD AND SUPERVISORY REQUIREMENTS FOR CONVENTIONAL ORGANIZATIONAL STRUCTURE

	Number of UE to be Deployed												
Squadron	16	18	24	32	36	48	54	56	64	72	84	90	96
Organizational Maintenance	24	24	30	31	33	46	47	49	54	61	70	72	74
Field Maintenance	11	11	11	11	13	15	16	17	17	18	22	23	24
Avionics Maintenance													
Conventional	9	9	9	10	10	13	14	14	14	15	16	16	16
Integrated	8	8	10	11	12	13	14	14	14	14	14	14	14
Munitions Maintenance	Determined by Munitions Manning equations												
Total[a]													
Conventional Avionics	44	44	50	52	56	74	77	80	85	94	108	111	114
Integrated Avionics	43	43	51	53	58	74	77	80	85	93	106	109	112

SOURCES: "Final Report, TAC Manpower Standards A-7D," 4400MES/LC, Langley Air Force Base, 18 June 1976, and "Standard Manpower Table, Avionics Maintenance Overhead/Supv Req (LCOM) (F-111, F-15 only)," TAC Headquarters, Langley Air Force Base.

[a]Excludes overhead and supervisory requirements for munitions maintenance, which are separately computed.

factors. MACO borrows the MANPOWER procedure of relating all maintenance officer requirements to UE. The numbers of officers required for various UE are shown in Table 13.

POMO Organizational Structure. The equations discussed above are for the conventional organizational structure. It is possible to redistribute the requirements defined by these equations so as to make them compatible with the organizational structure used by POMO or similar alternative maintenance concepts. We assume that the total manpower requirement is the same as for the conventional case, so that the only effect of the alternative structure is to assign different groups of personnel to different organizational units. POMO might affect the overall personnel requirement, but this has yet to be substantiated.

The requirement for Chief of Maintenance personnel is assumed to be the same under either the POMO or conventional organization, because the number of people being managed is the same. The size of the Alert Force is also taken to be unchanged; its personnel are part of the Aircraft Generating Squadron (AGS).

Table 13

OFFICER REQUIREMENTS FOR CONVENTIONAL ORGANIZATIONAL STRUCTURE

	Number of UE to be Deployed												
Squadron	16	18	24	32	36	48	54	56	64	72	84	90	96
Organizational Maintenance	2	2	3	3	3	5	6	6	6	6	6	6	7
Field Maintenance	2	2	2	2	3	5	5	5	5	5	5	5	5
Avionics Maintenance													
Conventional	2	2	2	2	2	5	5	5	5	5	5	5	5
Integrated	2	2	4	4	4	5	5	5	5	5	5	5	5
Munitions Maintenance	3	3	4	4	4	5	5	5	6	6	6	6	6
Chief of Maintenance	5	5	5	6	6	6	7	7	7	7	7	7	7
Total													
Conventional Avionics	14	14	16	17	18	26	28	28	29	29	29	29	30
Integrated Avionics	14	14	18	19	20	26	28	28	29	29	29	29	30

SOURCES: "Final Report, TAC Manpower Standards A-7D," 4400MES/LC, Langley Air Force Base, 18 June 1976, and "Standard Manpower Table, Avionics Maintenance Overhead/Supv Req (LCOM) (F-111, F-15 only)," TAC Headquarters, Langley Air Force Base.

Corrosion Control, Survival Equipment, NDI, AGE, and PMEL are work centers primarily involved in off-aircraft work. MACO therefore assumes that none of the manpower for these work centers is in the AGS. This is consistent with changes in the authorizations of PACAF and USAFE units that have switched to POMO or similar concepts. Corrosion Control and AGE personnel become part of the Equipment Maintenance Squadron (EMS) under POMO; personnel in Survival Equipment, NDI, and PMEL move to the Component Repair Squadron (CRS).

Munitions Maintenance manning is affected in three ways by POMO. Weapons Loading personnel become part of the AGS, because their work is performed on the flight line. Weapons Release and Gun Services perform both on- and off-aircraft work. Manning for these work centers is split between the AGS and the EMS. For want of better information, we assume that this manning is divided evenly between these squadrons. The remainder of munitions maintenance activity is off-aircraft work and is performed by the EMS.

The overhead and supervision personnel in organizational, field, and avionics maintenance are assumed to be distributed among the POMO squadrons in accordance with the rearrangement of the direct maintenance functions with which they are associated. An estimate of their POMO distribution is shown in Table 14, except for personnel associated with munitions. The

Table 14

OVERHEAD AND SUPERVISORY REQUIREMENTS FOR POMO ORGANIZATIONAL STRUCTURE

	Number of UE to be Deployed												
Squadron	16	18	24	32	36	48	54	56	64	72	84	90	96
Aircraft Generating Sqdn.	20	20	25	26	28	40	41	43	48	55	64	66	68
Equipment Maintenance Sqdn.[a]	4	4	5	5	6	7	7	7	7	7	8	8	8
Component Repair Sqdn.													
Conventional Avionics	20	20	20	21	22	27	29	30	30	32	36	37	38
Integrated Avionics	19	19	21	22	24	27	29	30	30	31	34	35	36
Total[a]													
Conventional Avionics	44	44	50	52	56	74	77	80	85	94	108	111	114
Integrated Avionics	43	43	51	53	58	74	77	80	85	93	106	109	112

[a]Excludes overhead and supervisory requirements for munitions maintenance, which are separately computed.

requirement for these personnel is computed as part of the total munitions manning requirement by the munitions equations described above.

The number of maintenance officers under POMO is assumed to be the same as for a conventional organization. The total for overhead and supervision personnel has been distributed among the POMO squadrons in accordance with the redistribution of the direct maintenance functions. The resulting POMO requirements are given in Table 15.

Table 15

OFFICER REQUIREMENTS FOR POMO ORGANIZATIONAL STRUCTURE

	Number of UE to be Deployed												
Unit	16	18	24	32	36	48	54	56	64	72	84	90	96
Aircraft Generating Sqdn.	2	2	3	3	3	5	5	5	5	5	5	5	6
Equipment Maintenance Sqdn.	3	3	4	4	4	5	6	6	7	7	7	7	7
Component Repair Sqdn.													
Conventional Avionics	4	4	4	4	5	10	10	10	10	10	10	10	10
Integrated Avionics	4	4	6	6	7	10	10	10	10	10	10	10	10
Chief of Maint.	5	5	5	6	6	6	7	7	7	7	7	7	7
Total													
Conventional Avionics	14	14	16	17	18	26	28	28	29	29	29	29	30
Integrated Avionics	14	14	18	19	20	26	28	28	29	29	29	29	30

Manhour Estimating Equations

For the LCOM manned work centers, the two basic elements of the manpower methodology of MACO are the estimation of workload, measured in manhours ($MMH_{y,b,w,u}$), and the conversion of workload to required manning ($WCMNG_{y,b,w,u}$). The workload is estimated in several parts, corresponding to specific types of maintenance activity: unscheduled maintenance, flightline inspections, major inspections, and servicing. Each is computed separately, by year, for each operating unit at each base.

Unscheduled On-aircraft Maintenance. Unscheduled maintenance can be divided into on-aircraft and off-aircraft work. The model considers these separately. Each is driven by LRU failures. The number of failures of LRU i in unit u during year y at base b is given by

$$FAIL_{i,y,b,u} = \frac{12(FH/MO)UE_{y,b,u}QPA_i}{MTBF_{i,y}}$$

$$(i = 1, 2, \ldots, NL)$$

where FH/MO = flying hours per month per aircraft, or (SR)(SL)(FDPM); QPA_p = quantity per aircraft, the number of item p units installed on each aircraft; and $UE_{y,b,u}$ is the number of unit equipment being supported at base b in year y for unit u. Also, $MTBF_{p,y}$ = the mean time between true failures, expressed in aircraft flying hours. MTBF is allowed to vary with time so as to represent reliability growth such as might result from either normal maturation or a specific reliability improvement program. NL is the number of LRUs on the aircraft.

For each LRU and each work center w we specify:

$PAMH_{i,w}$ = Preparation and access manhours for LRU i, the number of manhours required to gain access to LRU i and prepare to work on it.

RIP_i = Repair in place fraction, the fraction of failures of LRU i that are repaired on-aircraft.

$IMH_{i,w}$ = In-place repair manhours, the number of manhours required to repair LRU i on-aircraft.

$RRMH_{i,w}$ = Remove and replace manhours, the number of manhours required to remove LRU i and replace it with a working item.

$RTOK_i$ = Re-test OK fraction, the fraction of LRU i removals for which failure cannot be verified by later recheck.

The number of manhours required during year y at base b in work center w to perform unscheduled on-aircraft work on LRU i for unit u is then given by the sum of manhours associated with true failures and those associated with false removals:

$$ONMH_{i,y,b,w,u} = FAIL_{i,y,b,u}\left(PAMH_{i,w} + RIP_i IMH_{i,w} + (1 - RIP_i)RRMH_{i,w}\right)$$

$$+ \frac{FAIL_{i,y,b,u}\left(1 - RIP_p\right)\left(PAMH_{i,w} + RRMH_{i,w}\right)}{1 - RTOK_p}$$

$$= FAIL_{i,y,b,u}\left(PAMH_{i,w} + RIP_i IMH_{i,w} + (1 - RIP_i)\left(RRMH_{i,w} + \frac{PAMH_{i,w} + RRMH_{i,w}}{1 - RTOK_i}\right)\right)$$

This accounts for repair or replacement of failed items and for replacement of false removals. The total unscheduled on-aircraft workload for work centers not involved in engine removals is

$$TONMH_{y,b,w,u} = \sum_{i=1}^{NL} ONMH_{i,y,b,w,u} .$$

When unscheduled engine removal work is included, the total unscheduled on-aircraft workload for the work center becomes

$$TONMH_{y,b,w,u} = \sum_{i=1}^{NL} \left(ONMH_{i,y,b,w,u}\right) + \frac{12(FH/MO)UE_{y,b,u}EPA\left(ERMH_{w}\right)}{CMRI}$$

where EPA = Engines per application, the number of engines installed on each airframe;

$ERMH_w$ = Engine removal manhours, the number of manhours for engine removal for work center w;

and CMRI = the Combined Maintenance Removal Interval, the average number of engine operating hours between engine removals.

Unscheduled Off-aircraft Maintenance. The off-aircraft manhour total for the year for work center w to maintain LRU i for unit u at base b is given by

$$OFFMH_{i,y,b,w,u} = \frac{FAIL_{i,y,b,u}\left(1 - RIP_{i}\right)}{1 - RTOK_{i}} \left(BCMH_{i,w} + (1 - NRTS_{i} - BCR_{i})RMH_{i,w}\right)$$

where $BCMH_{i,w}$ = Bench check manhours, the number of manhours required for work center w to conduct a bench check of LRU i;

$RMH_{i,w}$ = Repair manhours, the number of manhours required by work center w to perform an off-aircraft repair of LRU i.

Because the LRU may be repaired either through repair of the LRU itself or by replacement of its component SRUs, then

$$RMH_{i,w} = LRMH_{i,w}\left(1 - \sum_{k=1}^{NS_{i}} P_{i,k}\right) + \sum_{k=1}^{NS_{i}} \left(RRMH_{p,w} + (1 - NRTS_{p})RMH_{p,w}P_{i,k}\right)$$

where k refers to the SRUs that constitute the subject LRU; i.e., k = 1,2,3,...,NS_i; and p refers to any part, either LRU or SRU.

Also, $RRMH_{p,w}$ = SRU replacement manhours, the number of manhours required by work center w to replace the kth SRU in LRU i;

$LRMH_{i,w}$ = the number of manhours required by work center w when LRU i is repaired other than by SRU replacement.

and $P_{i,k}$ = the probability of SRU replacement, the probability that a failure of LRU i will be corrected by a replacement of its kth SRU.

The total off-aircraft workload for work center w to support unit u at base b in year y is given from the above as

$$TOFFMH_{y,b,w,u} = \sum_{i=1}^{NL} OFFMH_{i,y,b,w,u} .$$

If the work center performs engine repair, then its off-aircraft workload is

$$TOFFMH_{y,b,w,u} = \sum_{i=1}^{NL} OFFMH_{i,y,b,w,u} + \frac{12(FH/MO)UE_{y,b,u}ERTS\left(ERPMH_w\right)}{CMRI}$$

Flightline Inspections. Three basic types of inspections are performed on the flight line. For MACO, these are referred to as the preflight, throughflight, and postflight inspections. The Air Force sometimes uses other terms, depending on the aircraft; but the nature of the inspections is the same for most aircraft. The preflight inspection is performed on each aircraft at the beginning of each day that the aircraft is scheduled to fly. The model assumes that all scheduled sorties are flown and that sorties are distributed evenly over all aircraft and over all days of the year. The number of preflight inspections performed in a year is then given by

$$PF/YR_{y,b,u} = (365.)UE_{y,b,u} \qquad \text{if } SR > 1.0$$

$$= (365.)UE_{y,b,u}\ SR \qquad \text{if } SR < 1.0;$$

where SR is the unit's sortie rate in sorties per day per aircraft. The postflight is performed after the last flight of each day for each aircraft. The number of postflight inspections in a year therefore equals the number of preflights in the year:

$$PO/YR_{y,b,u} = (365.)UE_{y,b,u} \qquad \text{if } SR > 1.0$$

$$= (365.)UE_{y,b,u}SR \qquad \text{if } SR < 1.0;$$

The throughflight inspection is performed following each sortie except the last sortie of each day for each aircraft—i.e., except each sortie followed by a postflight. The number of throughflights each year therefore equals the number of sorties flown minus the number of postflight inspections:

$$TF/YR_{y,b,u} = (365.)UE_{y,b,u}SR - \left(PO/YR_{y,b,u}\right)$$

$$= (365.)UE_{y,b,u}(SR - 1.0) \qquad \text{if } SR > 1.0$$

$$= 0.0 \qquad \text{if } SR < 1.0.$$

Given the average numbers of work center w manhours per preflight, throughflight, and postflight inspection (MH/PF_w, MH/TF_w, and MH/PO_w respectively); the total number of manhours spent in flightline inspections by this work center is given by

$$FLIMH_{y,b,w,u} = (PF/YR_{y,b,u})(MH/PF_w) + (TF/YR_{y,b,u})(MH/TF_w)$$

$$+ (PO/YR_{y,b,u})(MH/PO_w)$$

Major Inspections. Major inspections (the periodic, hourly postflight, and phase inspection) are conducted at regular intervals measured in flying hours (FHI) or calendar time (CTI). For any particular inspection type s, the number of inspections in year y at base b is

$$NI_{y,b,s,u} = \frac{12UE_{y,b,u}(FH/MO)}{FHI_s} \text{ , or}$$

$$NI_{y,b,s,u} = \frac{12UE_{y,b,u}}{CTI_s}$$

depending on whether the interval is measured in FH or months. The workload for work center w for all major inspections is then

$$MIMH_{y,b,w,u} = \sum_{s=1}^{NINSP} NI_{y,b,s,u}(MH/INSP_{s,w}) \text{ ,}$$

where $MH/INSP_{s,w}$ is the average number of manhours spent by work center w on an inspection of type s. Special inspections are handled in the model as types of major inspections. This requires that the interval between special inspections of a given type must be expressed in terms of equivalent calendar time or number of flying hours.

Servicing. The servicing workload used in MACO consists of manhours spent on servicing and ground handling tasks directly associated with launch and recovery of aircraft. Similar tasks associated with major inspections (e.g., towing, washing) are most effectively accounted for as part of the inspection workload. Other servicing work is not dealt with in MACO because it is included in the "indirect" workload that LCOM studies do not model. Because this work is not in the LCOM data base, it is not addressed by the MACO manning estimating equations and therefore should not be included in the input to the model. For a given year, base, and unit, the servicing manhours for work center w are computed as the product of flying hours and an input manhour per flying hour factor:

$$SMH_{y,b,w,u} = 12UE_{y,b,u}(FH/MO)(SMH/FH_w)$$

where SMH/FH_w is the input number of servicing manhours per flying hour for the work center. Particular care must be used in developing a value for this factor, because typical values taken directly from field data will not be appropriate. Systems such as the Maintenance Data Collection System can provide total servicing manhours, but they do not distinguish between manhours associated with launch and recovery tasks and other manhours.

Total Workload. The total workload for a work center for a year is the sum of the various unscheduled maintenance, inspection, and servicing workloads. The unscheduled workload in work center w at base b in year y can be evaluated as

$$UNSMH_{y,b,w,u} = TONMH_{y,b,w,u} + TOFFMH_{y,b,w,u} .$$

The total workload is then

$$MMH_{y,b,w,u} = UNSMH_{y,b,w,u} + FLIMH_{y,b,w,u} + MIMH_{y,b,w,u} + SMH_{y,b,w,u} .$$

Note that if two-digit work unit code MH/FH data is provided for each work unit code c, then the unscheduled workload is computed as

$$UNSCH_{y,b,w,u} = \left(\sum_{c=1}^{NWUC} FMH_{c,w} \left(MH/FH_c \right) \right) (FM/MO)12UE_{y,b,u} ,$$

where $FMH_{c,w}$ is the fraction of work unit code c MH that are charged to work center w. Typical historical values are shown in Tables 7 and 8. The total yearly workload is converted to manhours per sortie for use in the manning estimating equations:

$$MH/SOR_{y,b,w,u} = \frac{MMH_{y,b,w,u}}{12(S_{y,b,u})}$$

Manning Estimating Equations. Equations relating work center manning requirements, $WCMNG_{y,b,w,u}$, to workload were derived from LCOM results for the weapon systems and work centers shown in Table 16, which shows that few useful data were available for integrated avionics systems. For work centers in Avionics Flightline Maintenance, which perform the bulk of the on-aircraft work for integrated avionics, the available data are too limited to support the type of analysis done for this study. These work centers were treated separately, as described below. For the test station and Avionics AGE work centers, we assembled a usable data base by treating these individual work centers as members of a homogeneous population—data for the individual work centers were combined into a single data set.

The MANPOWER project examined a number of equation forms and demonstrated that, at least for aggregations of work centers, simple linear equations of the form

$$WCMNG = A + B(MH/SOR) + C(SR) + D(UE)$$

gave useful estimates. Analysis of the individual work centers therefore began with the examination of this form of equation. Not all independent variables were found to be significant for

Table 16

WORK CENTER COVERAGE OF LCOM STUDIES

Work Center	A-7D	A-10	F-4E	RF-4C	F-111D	F-16
	Weapon System					
Flight line	x	x	x	x	x	x
Inspection	x	x	x	x	x	x
Structural Repair	x	x	x	x	x	x
Jet Engine	x	x	x	x	x	x
Repair & Reclamation	x		x			
Fuel System	x	x	x	x	x	x
Electrical System	x	x	x	x	x	x
Pneudraulic System	x	x	x	x	x	x
Environmental System	x	x	x	x	x	x
Egress	x	x	x	x	x	x
Communications	x	x	x	x		
Navigation	x	x	x	x		
Electronic Counter-measures		x	x			
Inertial Navigation	x		x	x		
Automatic Flight Control	x	x	x	x		
Instruments	x	x	x	x		
Weapons Control	x	x	x			
Photograhic-Sensors	x	x	x	x		
Automatic Test Stations					x	x
Manual Test Stations					x	
Avionics AGE (Integrated Avionics)						x

each work center. Those that were not were discarded one at a time, until an acceptable equation was found. The computed coefficients were then subjected to an analysis of variance to determine whether each work center was indeed unique. Two or three work centers were found that did not have significantly different relationships between manning and the independent variables. Each of these sets of work centers was treated as a single population, and a single equation was taken to apply to all work centers in the set.

For the navigation work center, an analysis of variance confirmed that regression coefficients generated for the reconnaissance aircraft alone are significantly different from those generated for the sample of other aircraft. Two separate equations are therefore included in the model for this work center.

Although different equations with significantly different coefficients were similarly obtained for the inertial navigation work center, an alternative is preferred in this case. The two separate equations for inertial navigation include only one significant variable: the number of UE. For the entire data set (both reconnaissance and other aircraft) a second variable is significant: manhours per sortie. A single equation using these two variables has statistics extremely close to those of the two individual equations and has the additional advantage of providing direct sensitivity to the workload differences that distinguish the two classes of aircraft. For these reasons the single equation is used in MACO.

The photographic-sensor work center data also produced results in which the number of UE is the only significant independent variable in different equations for reconnaissance and other aircraft. An attempt to develop a single equation for this work center was not successful, however. As for the inertial navigation work center, the workload variable is significant for the combined sample; but in this case the mean absolute deviation for the single equation is greater than that of the separate equations. The deviation is particularly poor for the reconnaissance data points. The very large workload difference between the reconnaissance and non-reconnaissance aircraft apparently causes the workload term in the equation to take on values incompatible with the manning variations that occur with changes in UE. Two separate equations are therefore used in the model.

Although the MANPOWER study found linear equations to be acceptable, the log-linear form fit the data better and gave more sensitivity to sortie rate. This form can be expressed as:

$$\ln WCMNG_{y,b,w,u} = \ln A + B\left(\ln\left(MH/SOR_{y,b,w,u}\right)\right) + C(\ln SR) + D\left(\ln UE_{y,b}\right) .$$

This is a logarithmic transformation of the equation

$$WCMNG_{y,b,w,u} = A\left(MH/SOR_{y,b,w,u}\right)^{B} SR^{C} UE_{y,b}^{\;D} .$$

When a regression analysis was performed with this transformed equation in the present study, the resulting equations fit the data better than the linear equations in all but one case. For the Egress work center, the logarithmic-linear equation had inappropriate arithmetic signs. The linear equation was used for this work center in the model, and the logarithmic-linear equations form the basis of the estimating equations for all other work centers. The regression results are shown in Table 17.

Table 18 presents the forms of the equations actually used in the model. These equations are for the usual LCOM scenario of twelve hour shifts seven days per week, or 365.28 manhours per month. The manpower authorization that the Air Force would use is estimated by adjusting for actual personnel availability:

$$WCMNG = (365.28/PA)Y$$

where Y is the manning from Table 18. PA is typically 242 manhours per month, in which case WCNMG = 1.51(Y). The MANPOWER study found it necessary to place a lower limit on the manning levels computed from the regression equations, because of minimum manning levels used in some work centers. MACO accommodates minimum manning levels in the same way—at least six personnel are used for each work center in Field Maintenance and Avionics Maintenance. Whenever the value of WCMNG for one of these work centers is computed to be less than six, the computed value is replaced by six in later computations of total maintenance manning and base level maintenance manpower cost.

These equations are applied individually to each group of aircraft flying from a single peacetime or wartime location. The total requirement is the larger of the total peacetime and total wartime requirements. For a wing of three squadrons operating from a single peacetime base, the equations are applied once to the entire wing to compute the peacetime requirement

Table 17

Regression Results

Work Center	Eqn. Type[a]	Con- stant[b]	Coefficients[c] MH/SOR	SR	UE	Statistics[d] R^2	SEE	Dev.
Flightline	LL	-2.262	1.312	1.605	0.925	0.942	0.129	0.08
Structural Repair	LL	0.0	0.875	1.575	0.563	0.996	0.161	0.13
Repair & Reclamation	LL	0.0	1.012	0.0	0.612	0.996	0.179	0.13
Egress	L	0.0	2.641	3.905	0.0	0.978	0.834	0.14
Communications	LL	0.0	0.0	2.985	0.550	0.969	0.325	0.23
Electronic Countermeasures	LL	-1.410	1.657	0.0	0.734	0.985	0.115	0.07
Inertial Navigation	LL	-1.187	0.309	0.0	0.860	0.921	0.146	0.10
Automatic Flight Control	LL	1.947	0.425	2.010	0.0	0.678	0.288	0.20
Photographic & Sensors	LL	0.0	0.0	0.0	0.390	0.990	0.147	0.12
Avionics Shop	LL	0.0	0.434	0.0	0.733	0.979	0.469	0.39
Inspection/Fuel	LL	0.0	0.370	0.617	0.613	0.988	0.260	0.20
Jet Engine/ Weapons Control	LL	-0.635	0.908	1.484	0.730	0.955	0.170	0.11
Electrical/Pneu- draulic/Instru- mentation	LL	0.0	0.890	1.413	0.537	0.991	0.195	0.16
Environmental/ Navigation	LL	0.0	0.410	0.0	0.501	0.983	0.228	0.18

Table 17—continued

Work Center	Eqn. Type[a]	Constant[b]	Coefficients[c] MH/SOR	SR	UE	Statistics[d] R^2	SEE	Dev.
Navigation (Recon)	LL	0.0	0.0	0.0	0.450	0.992	0.178	0.12
Photographic & Sensors (Recon)	LL	0.0	0.0	0.0	0.939	0.997	0.226	0.16

[a]Equation types are linear (L) and logarithmic-linear (LL).

[b]The constant term for logarithmic-linear equations is given in logarithmic form.

[c]All non-zero estimated parameters are significant at at least the 95% significance level.

[d]The listed statistics are the coefficient of determination (R^2), the standard error of estimate (SEE, expressed as a number of men), and the mean absolute deviation (Dev., expressed as a fraction of observed value).

and once, twice, or three times, depending on the deployment plan, to compute the wartime requirement.

Table 18 does not include an equation for Avionics Flightline Maintenance, the aggregation of work centers that performs on-aircraft maintenance of integrated avionics systems. Each of these individual work centers maintains a set of aircraft components comparable to those maintained by one or more of the work centers associated with conventional avionics. For typical maintenance organizations, the corresponding work centers are:

Integrated Avionics	Conventional Avionics
Automatic Flight Control-Instruments	Automatic Flight Controls Instruments
Photographic/Sensors	Photographic/Sensors
Weapons Control-Inertial Navigation	Weapons Control Inertial Navigation
Communications-Navigation-Penetration Aids	Communications Navigation Electronic Countermeasures

The appropriate manning for integrated avionics work centers can be estimated as an average of the manning requirements computed from the equations for the corresponding conventional avionics work centers, with the MH/SOR variable based on on-aircraft manhours only. When this procedure is applied to the Automatic Flight Controls-Instruments and Weapons Control-

Table 18

MANNING ESTIMATING EQUATIONS

Work Center	Estimating Equation
Flightline	$Y = 0.105(MH/SOR)^{1.312}(SR)^{1.605}(UE)^{0.925}$
Structural Repair	$Y = 1.013(MH/SOR)^{0.875}(SR)^{1.575}(UE)^{0.563}$
Repair & Reclamation	$Y = 1.016(MH/SOR)^{1.012}(UE)^{0.612}$
Egress	$Y = 2.641(MH/SOR) + 3.905(SR)$
Communications	$Y = 1.054(SR)^{2.985}(UE)^{0.550}$
Electronic Countermeasures	$Y = 0.246(MH/SOR)^{1.657}(UE)^{0.734}$
Inertial Navigation	$Y = 0.308(MH/SOR)^{0.309}(UE)^{0.860}$
Automatic Flight Control	$Y = 7.304(MH/SOR)^{0.425}(SR)^{2.010}$
Photographic & Sensors	$Y = 1.011(UE)^{0.390}$
Avionics Shop	$Y = 1.116(MH/SOR)^{0.434}(UE)^{0.733}$
Inspection/Fuel	$Y = 1.034(MH/SOR)^{0.370}(SR)^{0.617}(UE)^{0.613}$
Jet Engine/ Weapons Control	$Y = 0.538(MH/SOR)^{0.908}(SR)^{1.484}(UE)^{0.730}$
Electrical/Pneudraulic/ Instrumentation	$Y = 1.019(MH/SOR)^{0.890}(SR)^{1.413}(UE)^{0.537}$
Environmental/Navigation	$Y = 1.026(MH/SOR)^{0.410}(UE)^{0.501}$
Navigation (Recon)	$Y = 1.016(UE)^{0.450}$
Photographic & Sensors (Recon)	$Y = 1.026(UE)^{0.939}$

Inertial Navigation work centers for two sizes of F-16 units, the results are within one man of the requirements established by F-16 LCOM studies.

A similar procedure can be used to represent the separation of on- and off-aircraft work that characterizes some alternative maintenance concepts such as POMO. For each work center it is necessary to identify comparable work centers in the conventional maintenance organization. The manning for the alternative work centers then can be computed from the appropriate manhour data with the estimating equations that apply to the conventional work centers.

DEPOT MAINTENANCE

The two principal general approaches to estimating the cost elements Depot Maintenance Manpower and Depot Maintenance Material are the ones used in the CACE model and the LSC model. The CACE approach is intended for use only at the total system level and thus cannot provide the kind of sensitivity to subsystem characteristics desired in the MACO model. The LSC approach is applicable to a more detailed analysis and is the basis for the depot maintenance cost methodology used in MACO, but the basic LSC approach is expanded to provide fuller cost coverage and modified to improve depot maintenance cost component visibility.

In MACO, total depot maintenance cost is computed as the sum of the costs of maintaining each of the separate components of an aircraft system, including (1) whole aircraft maintenance (programmed depot maintenance or PDM plus other maintenance activities involving the whole aircraft, such as analytical condition inspection), (2) engine overhaul (EOH), (3) repair of exchangeable components, and (4) repair of support equipment. The LSC approach is similar in that it estimates total aircraft depot maintenance cost as the sum of component maintenance costs. In LSC these component maintenance costs are generated by estimating the number of direct labor hours (DLH) required to perform repairs and applying labor cost-per-hour and material cost-per-hour factors. In MACO, direct labor hours are translated into depot manpower requirements, with direct and indirect/overhead requirements identified separately, and pay and allowance factors are applied to the manpower estimates. Material and other nonlabor costs are generated on a cost-per-hour or cost-per-repair basis or as a combination of the two. These differences in methodology are fairly small, but they provide a basis for (1) tying cost estimates for new systems to historical depot cost and repair-demand data, and (2) accounting for other cost driving factors in addition to weapon system characteristics (e.g., depot structure).

The MACO model provides a set of formulas for estimating depot maintenance cost for the various components and subsystems of an aircraft, but it does not provide estimating relationships for the factor values that must go into the formulas to make an estimate. Instead, the terms used in the formulas are defined explicitly in relation to the Air Force Depot Maintenance Cost Accounting/Production Report System (H036B), which is the basic source of historical information on the *cost* of depot maintenance for all items of equipment, and the D041 system (the same reporting system used as the basis for the MACO model's recoverable spares estimating methodology), which is the source of information on *demand* rates for depot repairs.

Before we describe the estimating methodology it will be useful to review the way in which depot maintenance services are provided and financed in the Air Force. The organizational structure is an important factor in determining which costs are variable (with changes in system R&M characteristics, force size, or utilization rates) and which are fixed or only partly sensitive to depot structure. An understanding of the financial structure of Air Force depot maintenance is necessary if historical depot cost and activity information are to be used to estimate the cost of future systems.

Depot Maintenance Organization and Financing

The services covered by depot maintenance include both organic and contract maintenance. Air Force civilian and military personnel perform organic maintenance in maintenance shops at five Air Logistics Centers (ALCs) and the Aerospace Guidance and Meteorology Center (AGMC).[3] These organic maintenance shops work on Air Force equipment, equipment owned by the Army and Navy, and equipment owned by foreign governments. Contract depot maintenance includes work done (on Air Force equipment) by Army and Navy maintenance facilities and that done by commercial contractors. The cost of depot maintenance work performed by the Air Force organically or on contract is funded by the Depot Maintenance Services portion of the Air Force Industrial Fund (DMS, AFIF), which is a special type of revolving fund that is not a part of regular Air Force appropriated funds. In effect, the Air Force acts as an industrial concern and sells maintenance services to various customers, who reimburse the DMS, AFIF (out of appropriated funds, for U.S. government customers, or in some form of cash, for customers outside the U.S. government) for the labor, materials, and other expenses used or incurred in doing the work.

When the Air Force owns an item of equipment to be overhauled, repaired, or modified by DMS, the customer or "buyer" is usually a system manager or item manager (SM/IM) in AFLC, and the "seller" is a maintenance manager in AFLC. The Air Force budget includes appropriated funds (in the O&M, AF appropriation) to pay the DMS, AFIF for depot maintenance work on Air Force equipment. In the F&FP, the resources associated with DMS, AFIF are accounted for under program element (PE) 72007—Depot Maintenance (IF). The O&M funds required to finance DMS work for Air Force equipment are accounted for under PE 72207—Depot Maintenance (Non-IF). Funds for Air Force Reserve (AFR), Air National Guard (ANG), and Airlift Services Industrial Fund (ASIF) aircraft are accounted for under separate PEs.[4]

DMS, AFIF uses a cost accounting system to identify costs incurred by AFLC to the individual part numbers repaired (or modified) by it. The information collected by this system is used to (1) establish the prices to be charged to customers to recover costs, (2) monitor performance and productivity of the workforce, and (3) provide a basis for future forecasts of workloads and costs. The accounting system recognizes both "funded" costs (those covered by DMS, AFIF) and "unfunded" costs (those financed out of other appropriations). Funded costs are included in the sales price for all DMS customers. Unfunded costs are recorded statistically and are included in the sales price only for sales other than to the U.S. government.[5]

The following categories of costs are funded by the DMS, AFIF:

1. Cost of organic depot maintenance, including:
   a. Civilian wages and salaries, including allowances for leave and Air Force contributions to employee benefits.
   b. Materials, supplies, and parts used (expense items).
   c. General and administrative (G&A) expense, which is the cost of management and support services, such as data services, accounting, and personnel, provided to the

[3]The five ALCs are Ogden, Utah; Oklahoma City, Oklahoma; Sacramento, California; San Antonio, Texas; and Warner Robins AFB, Georgia. AGMC is located at Newark Air Force Station, Ohio.

[4]The cost of depot maintenance for ANG equipment is funded by the O&M, ANG appropriation under PE 57112—Depot Maintenance (ANG). For AFR equipment, DM costs are funded by the O&M, AFR appropriation under PE 57115—Depot Maintenance (AFR). DM costs for ASIF aircraft are paid for by the ASIF and are shown as elements of cost under each of the various Airlift (IF) PEs in the F&FP.

[5]Revenues received for unfunded costs are returned to the U.S. Treasury or, if the appropriation can be identified, used to reimburse it.

Directorate of Maintenance by organizations supporting the entire depot facility.

d. Contractual services (organic support), which is the cost of locally procured support services, such as training, utilities, communications, and base maintenance, purchased from base activities or on contract.

e. Other costs, including civilian and military travel on temporary duty (TDY) and civilian permanent change of station (PCS) travel and transportation of household goods.

2. Costs of contract maintenance, including:

a. Contractor charges.

b. Consumable materials, whether purchased by the government and furnished to the contractor (GFM) or purchased through the contractor, and excluding investment material (exchangeable items).

The following categories of cost are carried as "statistical" costs but are not funded by DMS, AFIF:

1. Military pay and allowances.
2. Depreciation of plant and equipment used by DMS.
3. Exchange material "repair factor," which is a standard cost to repair lower indenture exchangeable items replaced in the process of repairing a higher indenture item. It is taken as the actual historical repair cost of the items or is computed as a fraction (.2 is the standard value) of the stock list price of the items.

Organic maintenance costs reported in the cost accounting system include both direct and indirect/overhead costs. Direct costs include direct labor (for DLH reported against the repair and maintenance of specific items), direct expense material, direct exchange material, and other direct costs (per diem and travel costs and contract services identified to specific repair workloads). Indirect/overhead costs include all other costs reported in the DMS, AFIF cost accounting system. Three levels of the latter are identified in local management reports: shop expense, shop support expense, and general and administrative (G&A). For purposes of DoD reporting, the first two categories are combined as "operations overhead," and the third is called "G&A overhead." Shop expense overhead includes indirect labor, material, and other costs incurred at the "production shop" level (the organizational units that do most of the actual repair work). Shop support expense is defined as labor, material, and other costs incurred at the next higher organizational level, including activities identified as Section Direction, Engineering/Planning, Scheduling, Quality, and Division Direction. G&A expense comprises the costs of management and support organizational units serving the entire depot maintenance activity at an ALC.[5]

General Considerations in the Estimating Methodology

The structure of the cost accounting system suggests three types of depot maintenance costs, each driven by different variables. Direct costs are driven primarily by system and item R&M characteristics (although the skills and tools available to the maintenance shops also can be important factors). Operations overhead expense can be considered a "variable" indirect

[5] *Depot Maintenance Service Air Force Industrial Fund Financial Procedures*, Headquarters Air Force Logistics Command, AFLCR 170-10, draft revised version of 28 August 1978.

cost—i.e., the cost will vary as a function of the direct workload, and the ratio of indirect to direct cost will depend upon the structure of the maintenance organizations involved (the ratio for aircraft maintenance shops will probably be different from that for engine, accessory, or avionics shops). G&A overhead is a "fixed" overhead cost—the overall level of G&A cost is driven primarily by the number of ALCs and their management and support structure (and by policy decisions as to which support costs should be prorated over the depot workload), and only very substantial changes in workload are likely to affect the total G&A cost.

In addition to considerations of depot structure, the MACO cost estimating methodology for depot maintenance is intended to permit users to derive most input values from historical data or to be able to evaluate or compare input values provided by a contractor (or other source) with historical experience. At present, no long term, regularly maintained data base and data retrieval system exist in the Air Force to provide all of the historical data that might be needed for this purpose. However, the data needed in the MACO methodology should all be capable of being extracted from existing AFLC financial, cost accounting, and other data systems. A number of depot and maintenance cost data consolidation and analysis efforts have been conducted at AFLC and elsewhere in the Air Force in support of recent weapon development programs and independent cost analyses; and the Air Force is in the process of building a maintenance cost data base for aircraft components. Hence data should be more readily available in the future. Also, a description such as the one provided here of how and what kinds of data are needed to serve a generalized life cycle analysis framework for depot maintenance cost should be useful in framing the data collection, retrieval, and analysis systems.

Four types of aircraft-related equipment maintenance were noted earlier: (1) aircraft PDM, (2) engine overhaul, (3) exchangeable item repair, and (4) support equipment repair. The way in which depot maintenance requirements are generated and satisfied differs somewhat for each of these, and they are discussed briefly below.

Aircraft PDM. Aircraft are generally programmed to be sent to the depot at specified calendar time intervals (isochronal scheduling). An aircraft that arrives at the depot for PDM is sent through a prescribed package of partial disassembly, inspection, repair, and reassembly. The content of the inspection-and-repair package varies over the life of the aircraft, and the calendar interval for a given aircraft type is usually extended as the aircraft system matures.

One difficulty that arises in trying to use historical data on aircraft PDM costs is that past PDM workloads may include unknown amounts of labor for the installation of aircraft modifications. Life cycle cost estimates normally should not include unspecified (and unknowable) future major modifications, although some level of effort for class IV (minor and safety-of-flight) modifications is usually included. For the most part, historical data do not fit this definition, and it is unwise to reshape LCC definitions to conform to the historical data by including unpredictable and highly variable levels of future major modifications for new aircraft systems. Consequently, estimates of PDM requirements in LCC estimates will be difficult to place in perspective by comparison with past data. The best means of alleviating this difficulty is to begin collecting information that separates PDM work from modification installation.

Airframe rework activities other than PDM are not explicitly addressed in MACO, but the PDM equations can be applied to them with only minor revisions.

Engine Overhaul. Engines are normally scheduled for overhaul on a flying-hour basis, with the maximum time between overhauls (TBO) being extended as the engine design matures. Overhaul consists of a complete disassembly of the engine, routing of its components to various other repair facilities, and reassembly of a "zero-timed" engine from like components and parts (most of which are not the same as those in the engine when it arrived at the depot). The zero-timed engine is theoretically capable of being operated for the full MTBO interval before being returned again for overhaul. Engine depot maintenance also includes less extensive repair activities, such as on-condition maintenance and installation of modifications to correct deficiencies or to improve engine performance. Most available data pertain to gross depot engine repair costs, with no separate identification of non-overhaul repairs. Where information is available to treat these costs separately, they should be so treated in estimates.[7]

As is the case with basic aircraft maintenance, the cost of installing modifications may be partially buried in other engine depot maintenance costs. This is less of a problem for engine maintenance cost estimating, because both performance-improvement and correction-of-deficiency modifications are included in the normally expected events during the life cycle of an aircraft engine. A new engine design is normally planned to "grow" (be improved in terms of both thrust and reliability) over its life, and Component Improvement funds are expended on development activities to assure this growth. Hence the inflation of engine depot maintenance cost data by the inclusion of modification installation does not cloud the utility of the historical data, because we should expect such costs to be incurred for new engine designs as well.

Exchangeable Item Repair. This includes the repair of exchangeable airframe accessories, engine accessories, and avionics components and parts. Most of these items are repaired on an unscheduled basis. The items arriving at a repair facility for depot maintenance include those shipped NRTS from organizational and field level maintenance squadrons (OFM) and those removed during other depot activities. Engine modules repaired individually instead of as parts of whole engine overhauls should be treated as exchangeable items.

Support Equipment Repair. This consists primarily of the repair of SE used by organizational and field level maintenance squadrons. The repair of depot level SE is included as part of the indirect or overhead cost of operating a depot maintenance shop unless the repair has to be done by a maintenance shop other than the one using the equipment.

Cost Estimating Methodology

In the MACO depot cost estimating methodology, the number of scheduled maintenance actions is computed from data on aircraft and engine inventory sizes, utilization rates, and the average intervals between PDMs and engine overhauls. Unscheduled activities depend on aircraft component failure rates, NRTS rates, and depot condemnation rates. SE repair depends on the SE inventory size and repair frequency factors. For each type of action, DLH per action are input. Manpower costs are based on the total DLH and manpower productivity rates (DLH/manmonth). The costs of indirect/overhead manpower and G&A also depend on factors of cost per DLH. The cost of depot material may be based on either cost per manhour or cost per repair.

Depot Repair Demands. For each of the four types of depot maintenance (whole aircraft, engine overhaul, exchangeables, and SE), the total workload is developed by combining unscheduled demand rates or scheduled maintenance parameters with estimated direct labor hours per repair:

$$\mathrm{DLH}_{i,y} = \mathrm{Repairs}_{i,y}(\mathrm{DLH\ per\ repair})_i$$

[7]For a more thorough discussion of engine depot maintenance and other engine life cycle costs, see J. R. Nelson, *Life-Cycle Analysis of Aircraft Turbine Engines*, The Rand Corporation, R-2103-AF, November 1977.

where $Repairs_{i,y}$ is the number of depot repairs for item type i, in year y. "Item" is generic and includes aircraft PDM, engine overhauls, exchangeable items, and SE going through depot repair. An exchangeable item may be construed to be an individual aircraft component (LRU or SRU), or an aggregation of individual components, depending upon the level of detail of interest to the user.

The number of aircraft PDMs in year y is given by

$$PDM_y = INV_y PDMF_y$$

where INV_y is the average inventory of aircraft (including non-UE aircraft) in year y, and $PDMF_y$ is the fraction of the inventory to be scheduled for PDM in year y. This value will be zero or low in the initial years and will be the reciprocal of the PDM interval (in years) during the years of full force operations.

The number of engine overhauls (EOH) in year y is

$$EOH_y = \frac{(FH/MO)EPA \sum_{b=1}^{NB} BUE_{y,b}}{ATBO_y}$$

where the numerator is the total engine operating hours for the fleet and $ATBO_y$ is the average time between overhauls, in year y, expressed in terms of engine operating hours. This value should grow as the engine design matures.

The number of exchangeable item repairs (EIR) for component p in year y is

$$EIR_{p,y} = \left(\frac{(1 - RIP_p)NRTS_p \sum_{b=1}^{NB} \sum_{u=1}^{NU_b} FAIL_{p,y,b,u}}{RTOK_p} + (FH/MO)QPA_p UF_p REPGEN_p \right) (1 - DCR_p) \sum_{b=1}^{NB} BUE_{y,b}$$

where $FAIL_{p,y,b,u}$ is the base failure rate for item p during year y at base b in unit u; $NRTS_p$ is the NRTS fraction for the item; RIP_p is the repair-in-place fraction; $RTOK_p$ is the re-test OK fraction; $REPGEN_p$ is the demand rate from PDM, engine overhaul, or Specialized Repair Activity work; and DCR_p is the depot condemnation rate.

The number of SE repairs in year y for SE type j is

$$SER_{j,y} = SEI_{j,y} SEF_j$$

where $SEI_{j,y}$ is the SE inventory for item j in year y, and SEF_j is the fraction of the inventory requiring depot repair in any year. The number of repairs for a given type of SE is assumed to be based on the total inventory of that type of equipment. Actual failure rates are probably based on operating hours, but the community's ability to estimate operating hours for SE is so poor that using hours to compute the number of repairs is not practical.

Manpower. Manpower requirements are based on the number of direct labor hours required to repair each item. The direct labor hours are translated into direct and indirect/overhead manpower requirements, based on historical experience, using depot manpower productivity rates (DLH per man).

$$DDM_y = \frac{DLH_y}{DMP} DDF$$

$$IDM_y = \frac{DLH_y}{DMP} IDF$$

where DDM_y and IDM_y are depot direct and indirect manpower in year y, DLH_y is the total depot labor hours, DMP is depot manpower productivity (available manhours per man per month), and DDF and IDF are the direct and indirect labor fractions (DDF + IDF = 1). The equations in Appendix B provide for separate calculation of manpower for PDM (DDMP, IDMP), engine overhaul (DDME, IDME), exchangeable item repair (DDMEI, IDMEI), and support equipment repair (DDMSE, IDMSE). The current standard for AFLC manpower productivity is 145 hours per man per month (1740 hours per year). For all of AFLC, approximately 60 percent of manhours are direct labor. Where direct and indirect manhour information for a particular maintenance shop (or for some broader category of maintenance activity) is available, peculiar direct/indirect factors should be used. Average P&A factors are applied to this manpower result.

Material. There are three alternatives for estimating depot material costs. One is a set of regression equations that is presented in the following section on Maintenance Material. The second is a cost-per-manhour rate, and AFLC publishes rates for various categories of maintenance. The third alternative is to compute material costs as a cost per repair, where the cost factor is a fraction of the item procurement cost. The method presented here is a combination of these last two; analysts may use whichever computational form is most appropriate for the particular cost estimating problem. The general form of the equation is

$$DMC_y = DLH_y LHMF + REPS_y MCF$$

where LHMF is the material cost per labor hour, $REPS_y$ is the number of repairs in year y, and MCF is the material cost-per-repair factor. The equations in Appendix B provide separate computations for PDM (PMC), engine overhaul (EMC), exchangeable item repair (EIMC), and support equipment repair (SEMC).

If cost rates and factors for unique categories of hardware or maintenance actions are used, this approach could reasonably well reflect the influence that design characteristics have on requirements for depot material. Without such detailed information, however, this approach may not be any more realistic than the regression equations presented below. We did not address the problem of defining a set of categories that will produce accurate, realistic estimates, but we recognize that this step is vital to an improved methodology.

Other costs. In general, the primary component of other costs is G&A expense. These costs are usually allocated to depot work at a cost-per-manhour rate. Rates vary from one ALC to another and are published by AFLC or can be derived from historical depot cost data. The general form of the equation is

$$ODC_y = DLH_y(GAF + OCF)$$

where GAF is the General and Administrative rate (per hour), and OCF is the rate for other costs. The equations in Appendix B provide separate computations for PDM (ODCP), engine overhaul (ODCE), exchangeable item repair (ODCEI), and support equipment repair (ODCSE).

MAINTENANCE MATERIAL

This section describes a methodology for forecasting spares or supply costs as a part of the total cost of ownership of a weapon system. It also describes a model for evaluating the support effectiveness of any given set of spares, thus relating cost to performance.

MACO considers two types of spare parts: recoverable or repair-cycle items and consumable or economic order quantity (EOQ) items. Recoverable spares constitute the most important segment of the Air Force inventory in terms of dollar value. These items fall into the two cost elements Initial Spares and Replenishment Spares. A cost for recoverable spares is computed for each year of operations. That cost is then included in the cost of either Initial Spares or Replenishment Spares; recoverable spares needed for the first two years of system operation are considered Initial Spares; those added to the inventory in later years are Replenishment Spares. These definitions are consistent with budget categories and CAIG definitions, although they do classify as replenishment all spares bought to support aircraft that enter the inventory during the third and later years of operation.

For recoverable spares, the proposed forecasting methodology is applied on an individual item basis. For each item, the cost is estimated as a function of the item reliability and maintainability as well as the planned operational program of the weapon system to which the item applies and the level of support effectiveness desired. For EOQ items, a more aggregate approach is used. The cost of consumable items is estimated from the projected level of repair activity (expressed in dollars) of recoverable items. Consumable materials are accounted for by cost elements Base Level Maintenance Material and Depot Maintenance Material.

For both types of spares, the model addresses Organization and Field Maintenance (OFM) requirements, the most significant portion of the total spares requirement. Omitted from consideration are spares needed for system modification and war reserve. Support equipment spares costs are also not included. Available methodologies for common SE spares tend to be too simplistic to be useful; estimation of the cost of peculiar SE spares is typically carried out by the contractor only after the weapon system has been defined in some detail.

This methodology has three particular characteristics resulting from the goal of generating realistic cost estimates. It approximates what the Air Force requirement computation process would produce for a new weapon system. It is commonly known that a requirement does not necessarily translate into a final cost figure. Nevertheless, it is the basis for the budget preparation and is presumed to be correlated with eventual spares expenditures. The method is able to relate the spares requirement or cost to the supply support effectiveness that it provides, thereby giving meaning to the cost estimate. Finally, the process is sensitive to changes in system design and in maintenance policies, so that the cost implications of such changes can be determined.

Principal input parameters include the unit price, failure rate, NRTS rate, and total condemnation rate of each item. Also required for each item are the base repair cycle time and order and shipping time for each base. Other input needed for each base are the number of UE aircraft and the local activity rate in flying hours per month per UE. For some calculations of the support effectiveness measures, identification of the LRU/SRU indenture relationships is needed.

The model estimates, by fiscal year, the quantity of each recoverable item needed, the total cost of recoverable items, the cost of either base-level EOQ items or all (base and depot) EOQ items, and three measures of supply support effectiveness. The total EOQ cost equation gives the user a second choice of method for estimating the cost of depot maintenance material. This cost can also be estimated using the cost factor approach presented above.

Recoverable Items

The model is designed for estimating the total dollar value of spares requirements generated by the Air Force Recoverable Item Requirements System (D041), which is the system the Air Force uses to organize requirements computations for all types of recoverable spares. The model estimates requirements by fiscal year.

This computational scheme is particularly useful in dealing with recoverable items for two reasons. As the name suggests, a recoverable item can generally be restored to a serviceable condition when it fails. Thus, in determining the requirement for a given fiscal year, one must take account of the available assets from the preceding year. The requirement for a given year is in fact the difference between the total required stock level for that year and the assets available from the immediately preceding year (which is equal to the previous year's total stock level less condemnation during the year). Toward the end of the system's operating life, the operating program can be expected to contract. In that event, the net requirement is positive only if the condemnations cannot be satisfied from the available assets of the preceding period. Computing the requirements by year provides the additional benefits of accommodating changes in program factors and maintainability and reliability and allowing costs to be separated into the cost elements Initial Spares and Replenishment Spares in a manner consistent with budgetary categories.

The required stock level for each year is the sum of the base stock level, depot stock level, and condemnations. The base stock level is the sum of the average pipeline quantity and a safety stock level. The stock level at base b in year y for an item designated as part p is

$$BSL_{p,y,b} = PL_{p,y,b} + SS_{p,y,b} \ .$$

LRUs are indicated by $p < NL + 1$, where NL is the total number of LRUs. In some equations applicable only to LRUs, the index i is used rather than p ($p = i$ for LRUs). The index k is used in some equations to refer to SRUs; for LRU i, $k = 1,2,\ldots,NS_i$, where NS_i denotes the number of SRUs in LRU i. It follows that for SRUs p is given by

$$p = NL + \sum_{n=1}^{i-1} NS_i + k \ .$$

These relationships between p and i,k are based on an ordering of LRUs and SRUs as illustrated in Table 19.

In the stock level equation PL is the pipeline quantity and SS the safety stock. The pipeline term is based on an average resupply time computed as a weighted average of base repair time and order and shipping time.

Table 19

ARRAY OF LRU AND SRU DATA

p(part)	i(LRU)	k(SRU)	Part Description
1	1	-	Unindentured LRU #1
2	2	-	Unindentured LRU #2
.	.	.	.
.	.	.	.
.	.	.	.
NUL	NUL	-	Unindentured LRU #NUL
NUL+1	NUL+1	-	Indentured LRU #1
NUL+2	NUL+2	-	Indentured LRU #2
.	.	.	.
.	.	.	.
.	.	.	.
NL	NL	-	Indentured LRU #NUL
NL+1	NUL+1	1	SRU #1 in LRU #NUL+1
NL+2	NUL+1	2	SRU #2 in LRU #NUL+1
.	.	.	.
.	.	.	.
.	.	.	.
NL+NS(1)	NUL+1	NS(1)	SRU #NS(1) in LRU #NUL+1
NL+NS(1)+1	NUL+2	1	SRU #1 in LRU #NUL+2
NL+NS(1)+2	NUL+2	2	SRU #2 in LRU #NUL+2
.	.	.	.
.	.	.	.
.	.	.	.
NL+NS(NL)	NL	NS(NL)	SRU #NS(NL) in LRU #NL

$$PL_{p,y,b} = \left[\left(1 - NRTS_p - BCR_p\right)BRT_{p,b} + NRTS_p OST_{p,b}\right]DDR_{p,y,b}$$

where $NRTS_p$ = the fraction of removed p items that are sent to the depot for repair; BCR_p = the base condemnation rate, the fraction of removed p items that are condemned at base level; $BRT_{p,b}$ = average base repair cycle time for items not condemned or sent to depot for repair; $OST_{p,b}$ = order and shipping time. $DDR_{p,y,b}$ is the daily demand rate, equated here to the average number of removals per day and computed from the item MTBF and the base activity level:

$$DDR_{p,y,b} = \frac{(FH/MO)BUE_{y,b}QPA_p\left(1 - RIP_p\right)}{30MTBF_{p,y}\left(1 - RTOK_p\right)}$$

where

$$BUE_{y,b} = \sum_{u=1}^{NU_b} UE_{y,b} ,$$

the number of UE being supported at base b; RIP repair in place fraction, the fraction of failures of LRU i that are repaired on-aircraft; RTOK the fraction of part p removals that cannot be later verified as failures in the shop; and a 30 day month is assumed.

The safety stock equation assumes the same 3-to-1 variance to mean ratio used in D041:

$$SS_{p,y,b} = PS \sqrt{3PL_{p,y,b}}$$

where the value of PS is established by the user. Normally, 1.0 should be used, because D041 usually uses that value. The depot stock level is set at 30 days of NRTS and base condemnations, as is done in D041. To support item i, the depot maintains a stock level given by

$$DS_{p,y} = 30TDR_{p,y}(NRTS_p + BCR_p)$$

where $TDR_{i,y}$ is the force-wide total demand rate defined as

$$TDR_{p,y} = \sum_{b=1}^{NB} DDR_{p,y,b} \ .$$

The condemnation requirement is simply the quantity needed to replace units that cannot be repaired at either base or depot levels:

$$COND_{p,y} = 365TDR_{p,y}(BCR_p + NRTS_p DCR_p) \ .$$

The total stock level for year y is then

$$TSL_{p,y} = DS_{p,y} + COND_{p,y} + \sum_{b=1}^{NB} BSL_{p,y,b} \ .$$

The number of units of item i that must be purchased to provide this stock level (the Recoverable Spares Buy) is

$$RSB_{p,y} = TSL_{p,y} - TSL_{p,y-1} + COND_{p,y-1}$$

$$\text{if } TSL_{p,y} - TSL_{p,y-1} > 0;$$

$$= \max\left[TSL_{p,y} - TSL_{p,y-1} + COND_{p,y-1},\ 0\right]$$

$$\text{if } TSL_{p,y} - TSL_{p,y-1} < 0.$$

The contribution of each item to the cost of recoverable spares is the product of the total quantity required and the item's unit price:

$$RSC_{p,y} = UP_p RSB_{p,y}$$

where UP_p is the unit price of item i. The recoverable spares costs in years 1 and 2 are classified as Initial Spares; costs for subsequent years are Replenishment Spares. Thus,

$$CIS_y = \sum_{p=1}^{NP} RSC_{p,y} \qquad \text{for } y = 1, 2$$

$$= 0 \qquad \text{for } y > 2$$

and

$$CRS_y = \sum_{p=1}^{NP} RSC_{p,y} \qquad \text{for } y > 2$$

$$= 0 \qquad \text{for } y = 1, 2 .$$

NP is the total number of distinct types of recoverable parts. Note that, for convenience, these equations ignore possible long lead times that could require funding before the year for which the spares are needed in the field. If the lead time is known, the equations should be revised accordingly.

Currently within the D041, the Air Force applies the so-called Variable Safety Level (VSL) method. In determining the mix of spares to be included in the total requirement, VSL considers individual unit prices. At every stage in the allocation of a fixed budget, its criterion is to select a particular spare that will give the maximum reduction in the system-wide shortages of spares per dollar of expenditures on spares. The resulting mix of spares is different from the one determined by the MACO approach. However, to apply the VSL methodology, a budget level has to be selected, and it is generally the same as the total spares cost determined by filling the pipelines in accordance with the MACO approach.

Support Effectiveness Evaluation Model

Three commonly used measures of supply effectiveness are the expected number of fills per item, expected backorders per demand, and expected NORS aircraft per squadron. These statistics are developed by MACO as aggregate measures of effectiveness across all bases.

Average Resupply Time. A key variable in these computations is the average resupply time, defined as the average time for a reparable item to be either repaired at the base or replaced by a serviceable item from the depot. Once the average resupply time is determined, calculations of the effectiveness measures can proceed.

The model evaluates the average resupply time differently depending on whether the item is an unindentured item or an indentured LRU. The average resupply time of the former depends on the stockage position of the item itself. For the latter, the average resupply time depends not only on the stockage position of the LRU, but also on the stockage positions of its SRUs. Let $ART_{p,y,b}$ be the average resupply time for an unindentured item p ($p \leq NUL$ or $p > NL$) at base b during year y. Then,

$$ART_{p,y,b} = (1 - NRTS_p - BCR_p)BRT_{p,b} + (NRTS_p + BCR_p)(OST_{p,b} + \Delta_{p,y}DRT_p)$$

where

$$\Delta_{p,y} = \frac{1}{Q1_{p,y}} \sum_{X=DS_{p,y}+1}^{\infty} (X - DS_{p,y})PR(X;Q1_{p,y})$$

and DRT_p is the average depot repair time for item p. The notation PR(X;Q) indicates the probability that X units are in resupply, given that demands have a Poisson distribution with mean Q:

$$PR(X;Q) = \frac{e^{-Q}Q^X}{X!} .$$

In the present case,

$$Q = Q1_{p,y} = DRT_p TDR_{p,y}$$

The above equation states that the average time required to turn a reparable item into a serviceable item is computed as a weighted average of the time required to accomplish a base level repair and the time required to obtain a serviceable replacement from the depot. The depot replacement time will always be at least equal to the average order and shipping time. Sometimes it will be greater, because the item must go through depot repair. The model computes the frequency of this event as a function of the depot stock level DS. When DS is large, the delay function Δ(DS) will be smaller. However, if DS is zero or very small, Δ(DS) will be 1.0 or very close to it. This will mean every requisition to depot will require at least the order and shipping time plus depot repair time.

For an indentured LRU ($NUL < p < NL + 1$), the average base repair time BRT has to be modified to reflect the delay due to the unavailability of the SRU needed for repair of the LRU. If the expected delay in LRU i base repair due to a backorder on its kth SRU at base b is represented by $DLY_{i,k,y,b}$, then

$$DLY_{i,k,y,b} = \frac{1}{DDR_{p,y,b}} \sum_{X=BSL_{p,y,b}+1}^{\infty} (X - BSL_{p,y,b})PR(X;Q2_{p,y,b})$$

where

$$Q2_{p,y,b} = TDR_{p,y}ART_{p,y,b}$$

Finally, the expected delay for indentured LRU i at base b due to a backorder of any of its SRUs is

$$LRUD_{i,y,b} = \frac{\sum_{k=1}^{NS_i} DDR_{p,y,b} DLY_{i,k,y,b}}{\sum_{k=1}^{NS_i} DDR_{p,y,b}}$$

This LRU delay term is added to the $BRT_{p,b}$ used in the $ART_{p,b}$ equation given above for the unindentured item; i.e.,

$$ART_{p,y,b} = (1 - NRTS_p - BCR_p)(BRT_{p,b} + LRUD_{p,y,b}) .$$

Measures of Supply Effectiveness. Given an average resupply time $ART_{p,y,b}$, three different measures of supply effectiveness can be computed. Each provides a yardstick for gauging a different aspect of the supply system performance.

The fill rate, the most commonly used criterion for judging supply performance, is the proportion of demands that can be honored immediately, utilizing serviceables on the shelf. In the Air Force, the target fill rate is approximately 80 percent. This statistic is calculated as an average over all bases.

For an individual base, the fill rate is

$$FR_{y,b} = \frac{1}{NP} \sum_{p=1}^{NP} \sum_{X=1}^{BSL_{p,y,b}} PR(X; QART_{p,y,b})$$

where

$$QART_{p,y,b} = DDR_{p,y,b} ART_{p,y,b} .$$

The average system fill rate is then

$$FILL_y = \frac{1}{NB} \sum_{b=1}^{NB} FR_{y,b} .$$

Fill rate does not have a time dimension. It does not take into account the duration of a backorder. In contrast, the backorder criterion measures backorder days. It considers equally serious one unit backordered for ten days and ten units backordered for one day. From the standpoint of inventory optimization, dealing with the backorder function is considered to be more desirable than the fill rate function by inventory theorists.

Again the statistics are computed as an average over all bases. Let $BO_{y,b}$ be the average backorders outstanding at base b. Then

$$BO_{y,b} = \sum_{b=1}^{NB} \sum_{X>BSL_{p,y,b}}^{\infty} (X - BSL_{p,y,b}) PR(X; QART_{p,y,b}) .$$

Normalizing by the expected daily demand gives

$$\frac{BO_{y,b}}{\sum\limits_{p=1}^{NP} DDR_{p,y,b}} ,$$

which has the dimension of delays per demand. Then the overall average is

$$BCKORD_y = \frac{1}{NB} \sum_{b=1}^{NB} \frac{BO_{y,b}}{\sum\limits_{p=1}^{NP} DDR_{p,y,b}} .$$

The statistic perhaps most meaningful to the operations side of the Air Force is the NORS rate, the number of Not Operationally Ready—Supply aircraft expressed as a fraction of total possessed aircraft. Although the NORS rate varies depending on the system, the Air Force has attempted to maintain a 5 percent NORS rate for mature systems. The probability of demand for item i not exceeding u units is

$$\sum_{X=1}^{u} PR\left(X; QART_{p,y,b}\right) .$$

If there are $BSL_{p,y,b}$ units of stock on hand and the number of applications per aircraft is QPA_p, and if there are C aircraft already down and available for cannibalization, then the probability that there are C or fewer NORS aircraft is

$$PNORS_{c,y,b} = \prod_{p=1}^{NP} \sum_{X=1}^{LIM} PR\left(X; QART_{p,y,b}\right) \qquad \text{where } LIM = BSL_{p,y,b} + QPA_p C .$$

The expected value of a nonnegative discrete random variable can be found by summing the complement of the cumulative probability distribution. The number of NORS aircraft is such a variable, so one can write its expected value for base b as

$$\sum_{c>-1} \left(1 - PNORS_{c,y,b}\right) .$$

The average fraction NORS, over all bases, is then

$$FNORS_y = \sum_{b=1}^{NB} \sum_{c=0}^{\infty} \frac{1 - PNORS_{c,y,b}}{BUE_{y,b}} .$$

Economic Order Quantity Items

An aggregate approach can be used for estimating the cost of economic order quantity (EOQ) items. Demands for EOQ items are assumed to be related to the rate of repair activities, which in turn is driven by reparable generations. Air-Force-wide data on reparable generations and EOQ demands for 1972 through 1976 were obtained from the Directorate of Logistics Operations, the Air Force Logistics Command. The data are presented in Table 20.

Regressing EOQ demands at base level on recoverable reparable generations, with both expressed in millions of dollars, produced the following linear equation:

$$BEOQC_y = -46.4 + 0.029 \sum_{p=1}^{NP} 365TDR_{p,y}(1 - BCR_p - NRTS_p DCR_p)UP_p \ .$$

This equation computes base level maintenance material cost for each fiscal year using the recoverable item spares cost developed as described above. The regression coefficient is statistically significant at the 90 percent level. The correlation coefficient is 0.74.

If the combined cost of base level maintenance material and depot maintenance material is desired, the equation to be used is

$$TEOQC_y = -29.9 + 0.039 \sum_{p=1}^{NP} 365TDR_{p,y}(1 - BCR_p - NRTS_p DCR_p)UP_p \ .$$

This equation is statistically significant at the 95 percent level with a 0.975 coefficient of determination. The cost of depot maintenance material alone is then the difference

$$TEOQC_y - BEOQC_y \ .$$

A more detailed approach to estimating this cost is presented above under Depot Maintenance costs. That procedure is more representative of the actual cause-effect relationship, but only when fairly detailed material cost rates are known. The regression equations presented here provide an alternative that is easier to use and more appropriate when detailed data are lacking.

Table 20

DATA FOR ESTIMATING COST OF EOQ ITEMS

	Activity by Class of Material[a]		
Year	Reparable Generations	Base Level EOQ Demands	Total EOQ Demands
1972	8989	236	n.a.
1973	9237	202	327
1974	7707	168	267
1975	8246	193	297
1976	8973	199	322

[a]Adjusted to millions of 1967 dollars using indices of industrial commodities developed by the Bureau of Labor Statistics.

Aggregate Approach

An aggregate approach to recoverable spares cost has not been developed for MACO, but an appropriate one could be produced through analysis of historical data. The subsystem or two-digit work unit code (WUC) level would be an appropriate level of detail and would greatly reduce the amount of data needed to produce a total system cost without eliminating all sensitivity to weapon system characteristics. An approach similar to the detailed spares methodology described in this section would not be practical, because two-digit data will not support a realistic representation of the flow of material through the various maintenance tasks.

A more fruitful approach might be to relate the total cost of spares for all items within a two-digit WUC to some aggregate measures of demand rate and unit price. Data for existing systems could be the source for the development of relationships based on, for example, the modes or medians of the distributions of demand rate and unit price within a two-digit WUC.

IV. MACO EQUATIONS FOR OTHER COST ELEMENTS

This section presents the cost estimating methodologies for the ownership cost elements not covered in the preceding section. These include Support Investment (other than Initial Spares), Sustaining Investment (other than Replenishment Spares), Wing/Base Level Operations and Support (other than Base Level Maintenance), Installation Support, and Personnel Support and Training. The cost estimating methodologies were adopted mostly from LSC and the BACE/CACE models. A few of the cost elements called for by the CAIG were omitted from MACO; they are discussed at the end of this section.

INVESTMENT METHODOLOGIES

Support Investment (Other than Initial Spares)

Support Equipment. The cost of common support equipment (SE) has been determined by AFLC[1] to be related to the flyaway cost of the aircraft supported. In year y, the cost of common SE is

$$CCSE_y = 0.01(FAC) \sum_{b=1}^{NB} BUE_{1,b}\ , \text{ if } y = 1;$$

$$= 0.01271(FAC) \sum_{b=1}^{NB} BUE_{1,b} + 0.01(FAC) \sum_{b=2}^{NB} BUE_{2,b}\ , \text{ if } y = 2;$$

$$= 0.005(FAC) \sum_{t=1}^{y} \sum_{b=1}^{NB} BUE_{t,b}$$

$$+ 0.00271(FAC) \sum_{t=1}^{y-1} \sum_{b=1}^{NB} BUE_{t,b}\ , \text{ if } 2 < y \leq YP;$$

[1] *A Guide for Estimating Aircraft Logistics Support Costs*, Headquarters, Air Force Logistics Command, AFLCP 173-3, 12 March 1974, p. 3.

$$= 0.00271(FAC) \sum_{t=1}^{y-1} \sum_{b=1}^{NB} BUE_{t,b} , \text{ if } y > YP.$$

In these equations y is counted from the first year of production, YP = the last year of production (assumed to be greater than 2), and FAC = the average aircraft flyaway cost. The index b ranges from 1 to NB, the number of operating bases.

For peculiar SE, the cost in year y, $CPSE_y$, is simply the product of the quantity procured that year, $PSEQ_y$, and the unit cost, PSEUC. Therefore,

$$CPSE_y = PSEQ_y PSEUC .$$

The total SE cost in year y is then

$$CSE_y = CPSE_y + CCSE_y .$$

Spare Engines. The spare engine calculations in the LSC model are a close match for the procedures used by AFLC to compute requirements for conventional engines. For this reason, the LSC approach matches the requirements for MACO and has been used in the new model.

Spare engines are bought once, at the beginning of the operational life of the aircraft. The cost of those engines is given by[2]

$$CSPE_y = (LS(BPQ) + DOQ)EUC, \qquad \text{if } y = 1$$

$$= 0.0, \qquad \text{otherwise;}$$

where LS = the number of engine stockage points,
BPQ = the base level pipeline quantity, the number of whole spare engines needed to fill the base level portion of the engine pipeline;
DOQ = the depot overhaul quantity, the number of engines needed to fill the depot overhaul cycle; and
EUC = the engine unit cost.

BPQ is the minimum value of X for which the probability that the number of items demanded during the base pipeline time does not exceed X is at least equal to CONF. CONF is a confidence level selected by the user. Demands are assumed to have a Poisson distribution.

$$\sum_{n=0}^{X} e^{-ARGB} \frac{ARGB^n}{n!} \geq CONF ,$$

where

$$ARGB = \frac{PFFH(EPA)}{LS(CMRI)} (ERTS(BP) + (1 - ERTS)ARBUT)$$

[2]This methodology is adopted from the *Logistics Support Cost Model User's Handbook*, August 1976.

In this expression,

PFFH = peak force flying hours

$$PFFH = (FH/MO) \max \left[\sum_{b=1}^{NB} BUE_{y,b} \right]$$

EPA = the number of installed engines per aircraft,
CMRI = the Combined Maintenance Removal number of engine operating hours between engine removals;
ERTS = the fraction of removed engines that are returned to serviceable condition by base maintenance,
BP = the number of months in the base repair cycle,
and ARBUT = the Engine Automatic Resupply and Buildup Time, in months.

Similarly,

$$\sum_{n=0}^{X} e^{-ARGD} \frac{ARGD^{n}}{n!} > CONF ,$$

where

$$ARGD = \frac{PFFH(EPA)}{CMRI} (1 - ERTS)DP.$$

Here DP = depot engine repair cycle time, in months.

Sustaining Investments

The various Sustaining Investment costs are estimated as in the CACE model.

Modifications. The cost of modifications is derived from the aircraft flyaway cost. This is insensitive to many factors that may drive individual modification programs, but may have value for some total-force decision problems. The cost for year y is

$$CMOD_{y} = FAC(MODF) \sum_{b=1}^{NB} BUE_{y,b}$$

where MODF is provided by the user. The CACE model currently uses MODF = 0.004494.

This methodology is suitable only at the total force level; it is included in the model only because the nature of modification programs is such that a meaningful model of the modifications cost of individual systems is not likely to be developed in the near future.

Replenishment Support Equipment. The cost of common support equipment replenishment in year y is

$$CRSE_{y} = (SE/UE) \sum_{b=1}^{NB} BUE_{y,b}$$

where SE/UE is a dollars per UE factor supplied by the user.

Training Ordnance. The cost of Training Ordnance is derived from the number of UE and the number of aircrews.

$$CTO_y = \sum_{b=1}^{NB} BUE_{y,b}(TOUE + CR_b TOCRW) .$$

Both TOUE and TOCRW are cost factors provided by the user.

WING/BASE LEVEL OPERATIONS AND SUPPORT

This section addresses the elements of operating and support cost that are incurred by aircraft organizations at wing/base level. These organizations fly the aircraft and also command, manage, and support the people, facilities, and equipment needed at base level either to maintain peacetime proficiency training or provide the necessary capabilities for wartime deployments. Two elements of wing/base level costs—base level maintenance manpower and maintenance material—were addressed earlier. This section covers the remaining wing/base level cost elements, which are listed in Table 21.

Table 21

WING/BASE LEVEL OPERATING AND SUPPORT COST ELEMENTS (EXCLUDING BASE LEVEL MAINTENANCE MANPOWER AND MATERIAL)

Wing Operations
- Aircrews
- Command Staff
- Security
- Other Wing Manpower
- POL
- Miscellaneous O&M

Installations Support
- (includes base operations and real property maintenance activities)

Wing/Base Organization

USAF organizational structure at base level is set forth in AFM 26-2.[3] A typical tactical fighter wing/base organization would include the following organizational units:

1. Tactical Fighter Wing (Wing Hq)
2. Tactical Fighter Squadrons (Mission Squadrons)
3. Maintenance Squadrons
4. Combat Support Group (Group Hq)
5. Communications Squadron
6. Civil Engineering Squadron

[3] *Organization Policy and Guidance*, Air Force Manual 26-2, 7 May 1970.

7. Supply Squadron
8. Services Squadron
9. Security Police Squadron
10. Transportation Squadron
11. Base Hospital

A wing with a different mission (e.g., Tactical Training, Tactical Reconnaissance) would have a different set of mission squadrons in place of Tactical Fighter Squadrons, but the rest of the organizational structure would be the same. In terms of program elements in the F&FP, most of the personnel and costs of the wing/base level units are identified with the appropriate Primary Program Element (PPE) or with an Installations Support program element (Base Operations, Base Communications, or Real Property Maintenance Activities). The cost of the Base Hospital is identified primarily with the Care in Defense Facilities program element, and a portion of the Communications Squadron is identified with AIRCOM—a USAF-wide communications program element.

It is useful to align the organizational units with the cost elements listed in Table 1, particularly those elements that represent personnel costs. Wing headquarters is divided primarily among three cost elements: (1) Maintenance Manpower (Chief of Maintenance functions); (2) Command Staff (Command, Safety, Operations Staff, and other functions charged to the PPE); and (3) Installations Support (all other base management and administration functions, which are charged to Installations Support PEs). Mission squadrons include personnel in the Aircrews and Command Staff cost elements. The mission squadrons may also include personnel costs in the Other Wing Manpower cost element. Maintenance squadrons are almost wholly accounted for in the Maintenance Manpower cost element, the primary exception being the Base and Transient Aircraft Maintenance function (FAC 225x), which is a part of Installations Support cost. The portion of the Security Police squadron that is concerned with aircraft and weapons security (Aerospace Systems Security, FAC 435x-438x) and is charged to the PPE is included in the Security cost element. All other Security Police functions, the Combat Support Group, and other base support squadrons (except the Base Hospital and the AIRCOM communications functions) fall under the Installations Support cost element.

In the estimating equations shown below for wing/base level operations and support cost elements, we have based the form of the equations and most of the suggested factor values on the BACE/CACE models in AFR 173-10 and on an examination of USAF manpower authorizations—by base, organization, functional account code (FAC), and program element, as shown in in the Hq. USAF Manpower Authorization File. The most recent updating of manpower factors in AFR 173-10 took place in 1975. Our analysis of authorizations was also based on FY 1975 data. Although we believe the form of the equations is applicable to a wide variety of LCC estimating problems, the factor values suggested may not all be appropriate for current studies. Therefore, the basis for the factor values is given in the discussion that follows so that an analyst may use a similar process to derive factors from more current data or from data using more appropriate analogous systems.

Aircrews

Aircrews are programmed on the basis of a crew ratio (number of crews per UE aircraft) and crew composition (number of pilots, navigators, etc. per crew). The crew ratio is a key factor in an aircraft system's capability—it is a major determinant of the wartime sortie capability for the squadron.

The number of aircrew members needed at base b in year y is:

$$CREW_{y,b} = BUE_{y,b} CRT_b CSZ$$

where CRT_b is the crew ratio and CSZ is the number of personnel per crew (crew size). The cost of the aircrews is then:

$$CAC_y = \sum_{b=1}^{NB} CREW_{y,b} OPA$$

where OPA is the worldwide average pay and allowance rate for officers. Note that the crew ratio may vary from one base to another. In particular, the crew ratio for combat crew training (CCT) units will usually differ from that for mission units.

The cost of the three other wing/base manpower categories, below, is computed in a way similar to that for Aircrews—as the sum of the number of officers, airmen, and civilian personnel in the category, multiplied by the appropriate worldwide average pay and allowances rate. In the discussion below, only the equations for calculating the number of personnel in the category, by base and year, are shown. The cost equations follow directly from these.

Command Staff

The formal definition of Command Staff manpower includes specific functional categories in the mission squadrons and wing headquarters (mission unit command and administration, FAC 3100, 3101, 3701, etc.; and wing command, FAC 1010, flight safety, FAC 1061, and operations staff, FAC 13xx excluding 1311 and 1330). All other functions charged to the PPE in the mission squadrons and wing headquarters (and not already accounted for under the Aircrews or Maintenance Manpower categories) are defined as Other Wing Manpower. However, the dividing line between Command Staff and Other Wing Manpower is rather arbitrarily drawn, and both categories make use of MACO estimating equations consisting of a fixed number of personnel per (mission) squadron plus a fixed number of personnel per wing/base. The factor values shown below for Command Staff use somewhat expanded definitions for Command Staff. They include all functions that, on the basis of FY 1975 authorizations, are common to all or most tactical wing organizations, including some that would fall under the formal definition of Other Wing Manpower.

The estimating equations for the number of Command Staff officers, airmen, and civilians at base b in year y are:

$$CSO_{y,b} = CSOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSOWG_b WG_{y,b}$$

$$CSA_{y,b} = CSASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSQWG_b WG_{y,b}$$

$$CSC_{y,b} = CSCSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSCWG_b WG_{y,b} ,$$

where the number of wings on base b is

$$WG_{y,b} = 1, \text{ if } \sum_{u=1}^{NU_b} SQ_{y,b,u} > 0$$

$$= 0, \text{ if } \sum_{u=1}^{NU_b} SQ_{y,b,u} = 0 .$$

Typical values for the constants in these equations, based on FY 1975 authorizations for USAF tactical fighter and reconnaissance wings are:

CSOSQ = 3	(range 2 - 4)
CSASQ = 13	(range 10 - 18)
CSCSQ = 0	
CSOWG = 36	(range 30 - 43)
CSAWG = 42	(range 26 - 60)
CSCWG = 8	(range 0 - 18)

The mission squadron functions covered by these factor values are: FAC 3100-3101 or 3701, unit command and administration; FAC 3102, unit aircrew life support; FAC 5310, flight medicine (in CONUS based units); and FAC 3500 and 3580, operational unit intelligence (in overseas based units). The wing headquarters functions covered are: FAC 1010, command; FAC 106x, safety (overseas bases usually charge various ordnance safety functions, in addition to 1061 Flight Safety, to the PPE); FAC 13xx, operations staff, including 1330 operational training; and FAC 3500, 3540, 3580, photo/radar intelligence and operational unit intelligence charged to the PPE. A few other functions in the mission squadrons and wing headquarters are also charged to the PPE, but they are less regular in their occurrence than those listed above. They are discussed under the Other Wing Manpower category.

Security

The functions normally included in the Security cost element for tactical aircraft systems are FAC 435x, aircraft security, and FAC 438x, nuclear weapon storage area security. The estimating equation used in MACO is the same as the (implicit) relationship in the CACE model—a fixed number of personnel per squadron. The equations for the number of officer and airman personnel (civilian personnel are not used for this function) in Security at base b in year y are:

$$SECO_{y,b} = SECOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u}$$

$$SECA_{y,b} = SECASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u}$$

Our examination of FY 1975 authorizations indicated that the number of officers per squadron is almost always zero (the few officers in the Security Police function are usually charged to a Base Operations program element). The number of Security airmen varied enormously from base to base (from zero to almost 300) and was not well explained by a simple personnel-per-squadron factor. The value suggested in AFR 173-10 for most tactical fighters is 45 airmen per squadron, a value that was near the average for F-4 squadrons in FY 1975 but was high for other tactical aircraft systems.

Factors other than force size are quite important in determining the number of Security personnel required for a tactical aircraft system. One important factor is the number of aircraft on alert; another is the security requirement for nuclear storage areas. In general, the closer aircraft are based to areas where they could be directly engaged by enemy forces, the more security guards are required. For most LCC studies, the factors that most affect Security requirements are fixed (or vary in proportion to force size). Hence a simple personnel-per-squadron factor is usually suitable. In cases where the proportion of alert, forward based, or nuclear-armed aircraft in the force may vary, a submodel for estimating Security manpower requirements based on these factors should be developed in consultation with the Air Force Manpower Personnel, and Training offices responsible for setting security standards.

Other Wing Manpower

The equations for the number of officers, airmen, and civilian personnel in the Other Wing Manpower category at base b in year y are:

$$OWO_{y,b} = OWOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWOWG_b WG_{y,b}$$

$$OWA_{y,b} = OWASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWAWG_b WG_{y,b}$$

$$OWC_{y,b} = OWCSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWCWG_b WG_{y,b} .$$

Factor values for this category are peculiar to the aircraft system being studied. Our examination of FY 1975 authorizations showed some functions in the mission squadrons and wing headquarters that were present in most tactical aircraft organizations but varied by base location or aircraft type. For tactical fighters, CONUS bases usually had a small number of personnel (2 to 10 airmen per wing) in FAC 3280, Armament Recording Systems Support. Overseas bases usually had 8 to 10 airmen in FAC 3030, Synthetic Trainees. Obviously these functions might also be required for a new aircraft system, but the number of personnel required would depend upon the way in which the armament recording systems (gun cameras) and synthetic trainers were used.

Authorizations for RF-4 aircraft (and, presumably, for any new reconnaissance aircraft) include mission squadron and Reconnaissance Technical squadron personnel responsible for processing the data collected by the aircraft. Factor values for these functions, based on the FY 1975 data, are:

$$OWOSQ = 6 \qquad OWOWG = 6$$

$$OWASQ = 83 \qquad OWAWG = 52$$

A new reconnaissance aircraft, with different information processing procedures and technology, would probably have different manpower requirements, but the RF-4 factors can serve as a point of departure.

POL Cost[4]

For year y, the cost of POL is:

$$CPOL_y = \sum_{b=1}^{NB} 12BUE_{y,b}(FH/MO)(GAL/FH)(POLC/GAL)$$

where GAL/FH is the fuel consumption rate (gallons per hour) and POLC/GAL is the cost of one gallon of fuel. GAL/FH and POLC/GAL are both supplied by the user.

Wing Miscellaneous Operations and Maintenance

Miscellaneous Operations and Maintenance cost includes all PPE costs in the Operations and Maintenance appropriation that are not accounted for in other categories (i.e., in Base Level Maintenance Material or in civilian pay for one of the wing manpower categories). The BACE model has a cost element called PPE Miscellaneous Support that corresponds to this category in MACO. The CACE model has no corresponding category.[5] The cost is estimated at a cost per manyear rate:

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[4]The simple algorithm shown here is suitable only for planning studies in which information about aircraft mission usage and flight profiles is not available. Algorithms that reflect differences in POL usage as a function of flight profile are strongly preferred.

[5]The CACE model "BOS/RPM Support" category applies only to the Installations Support portion of nonpay O&M costs.

$$CWMOM_y = MOMF \sum_{b=1}^{NB} (CREW_{y,b} + WOO_{y,b} + WOA_{y,b})$$

where WOO is the number of officers and WOA the number of airmen in the Command Staff, Security, and Other Wing Manpower categories:

$$WOO_{y,b} = CSO_{y,b} + SECO_{y,b} + OWO_{y,b}$$

$$WOA_{y,b} = CSA_{y,b} + SECA_{y,b} + OWA_{y,b} \ .$$

MOMF is the PPE miscellaneous O&M cost factor input by the user. The value for this variable in the BACE model is $118.5 (15 percent of $790; no base year for the dollars is stated). The factor value should be derived from current O&M data on base level costs charged to tactical aircraft PPEs.

Base Level Maintenance Miscellaneous O&M

This cost element is computed in the same way as the Wing Miscellaneous O&M category:

$$CMOM_y = MOMF\left(MTA_y + \sum_{b=1}^{NB} OFCRM_{y,b}\right) \ .$$

Section IV provided the computations for number of maintenance airmen, MTA_y, and number of maintenance officers, $OFCRM_{y,b}$.

INSTALLATIONS SUPPORT

Installations Support cost is the sum of the pay costs for installations support personnel and miscellaneous O&M costs charged to BOS and RPM program elements:

$$TIS_y = ISP_y + ISOM_y \ .$$

The number of installations support personnel is estimated with the methodology presented in AFR 173-10. The numbers of installations support officers, airmen, and civilians are given by:

$$ISO_y = 0.00312(PPEO_y + PPEA_y)$$

$$ISA_y = 0.12636(PPEO_y + PPEA_y)$$

$$ISC_y = 0.02652(PPEO_y + PPEA_y) .$$

PPEO and PPEA are the numbers of PPE officers and airmen:

$$PPEO_y = \sum_{b=1}^{NB} (CREW_{y,b} + WOO_{y,b} + OFCRM_{y,b})$$

$$PPEA_y = MTA_y + \sum_{b=1}^{NB} WOA_{y,b} .$$

The fractional values used in the equations above are based on the AFR 173-10 factors for BOS/RPM manpower for General Purpose Forces bases. They represent the estimated incremental Installations Support personnel required for each additional direct (PPE) military person. The number of direct personnel is used as a proxy measure for the size of the operation to be supported on a base. Installations Support includes more than just personnel support functions.

The cost of Installations Support personnel is given by:

$$ISP_y = ISO_y OPA + ISA_y APA + ISC_y CIVP$$

where OPA, APA, and CIVP are worldwide average pay and allowance rates for officers, airmen, and civilians, respectively.

The miscellaneous (nonpay) O&M costs of Installations Support are estimated at a cost per manyear rate, where both PPE and Installations Support personnel are counted in the manyears:

$$ISOM_y = ISF(PPEO_y + PPEA_y + PPEC_y) + ISF(ISO_y + ISA_y + ISC_y)$$

where ISF is the Installations Support miscellaneous O&M cost factor. The CACE model rate for TAC, in FY 1977 dollars, is \$768. The same rate applies to PACAF, and the rate for USAFE is \$589. $PPEC_y$ is the number of PPE civilians:

$$PPEC_y = \sum_{b=1}^{NB} (MTC_{y,b} + CSC_{y,b} + OWC_{y,b}) .$$

$MTC_{y,b}$ is the number of civilians in the maintenance organization at base b in year y, which is usually small for tactical aircraft. This parameter can be taken to equal zero; or, alternatively, some small fraction of the number of maintenance airmen computed as in Sec. III may be taken to be civilians. The CACE model formulation for BOS/RPM miscellaneous O&M cost is used here instead of the BACE formulation, because the CACE factors are based on an actual study of BOS/RPM nonpay O&M costs. The derivation of the BACE factors for this cost category is unknown.

PERSONNEL SUPPORT AND TRAINING

The separate elements under Personnel Support and Training are estimated using methodologies extracted from CACE.

Individual Training

The cost of Individual Training is composed of two parts: the cost of acquiring personnel and the cost of their training. Five categories of personnel are provided for:

1. The number of pilots in year y is

$$PLT_y = PPC \sum_{b=1}^{NB} BUE_{y,b} CRT_b$$

where PPC is the number of pilots per crew.

2. The number of other rated officers in year y equals the difference between the total number of crew members and the number of pilots:

$$ORO_y = (CSZ - PPC) \sum_{b=1}^{NB} BUE_{y,b} CRT_b \; .$$

3. The number of nonrated officers in year y is the total number of PPE, Installations Support, and medical officers less the number of rated officers:

$$NRO_y = PPEO_y - PLT_y - ORO_y \; .$$

4. The number of airmen in aircraft maintenance is determined as described in Section III for individual work centers and bases. The total number is given by

$$MTA_y = \sum_{b=1}^{NB} \left(OHSM_{y,b} + \sum_{w=1}^{NWC} WCM_{y,b,w} \right) .$$

5. The number of airmen not assigned to aircraft maintenance is the difference between the total requirement for PPE, Installations Support, and medical airmen and the number of airmen in maintenance:

$$NMA_y = PPEA_y + ISA_y + MA_y - MTA_y \; .$$

Three input parameters are required for each of these categories of personnel. A turnover factor specifies the fraction of the number of personnel in each category that must be replaced each year. An acquisition cost factor is measured in dollars per man acquired. A training cost factor gives the marginal training cost per graduate. These factors are designated as in Table 22.

The total cost of Individual Training for year y is then found by combining the number of personnel in each category for that year with the appropriate set of input factors. Thus,

$$\begin{aligned} CIT_y = {} & PLT_y PLTO(PLTACQ + PLTTRG) + ORO_y OROTO(OROACQ + OROTRG) \\ & + NRO_y NROTO(NROACQ + NROTRG) + MTA_y MTATO(MTAACQ + MTATRG) \\ & + NMA_y NMATO(NMAACQ + NMATRG) \; . \end{aligned}$$

Table 22

INDIVIDUAL TRAINING INPUT FACTORS

Personnel Category	Turnover Rate	Acquisition Cost	Training Cost
	Input Factors		
Pilots	PLTTO	PLTACQ	PLTTRG
Other rated officers	OROTO	OROACQ	OROTRG
Nonrated officers	NROTO	NROACQ	NROTRG
Maintenance airmen	MTATO	MTAACQ	MTATRG
Nonmaintenance airmen	NMATO	NMAACQ	NMATRG

Health Care

The cost of health care depends on the number of personnel associated with the Primary Program Element, Installations Support and Health Care:

$$CHC_y = OHCR(PPEO_y + ISO_y + MO_y) + AHCR(PPEA_y + ISA_y + MA_y)$$

$$+ MO_y OPA + MA_y APA + ISF(MO_y + MA_y) .$$

MO and MA are the numbers of medical officers and airmen:

$$MO_y = 0.0057(PPEO_y + PPEA_y + ISO_y + ISA_y)$$

$$MA_y = 0.0167(PPEO_y + PPEA_y + ISO_y + ISA_y) .$$

The coefficients in these equations were developed for TAC; comparable values have been developed for some, but not all, other commands. OHCR and AHCR are marginal health care rates in dollars per manyear, for officers and airmen respectively.

Permanent Change of Station

The cost of PCS moves, like the cost of health care, uses cost per manyear factors:

$$CPCS_y = OPCSR(PPEC_y + ISO_y + MO_y) + APCSR(PPEA_y + ISA_y + MA_y) .$$

OPCSR and APCSR are input factors expressed in dollars per manyear for officers and airmen, respectively. Greater accuracy can be achieved by using separate factors for overseas bases and bases in the United States, which would require computing subtotals of manyears for overseas and U.S. bases.

OMITTED COST ELEMENTS

Six of the ownership cost elements collected by the CAIG were not considered appropriate for inclusion in MACO. Training Equipment and Services and Documentation costs depend to a great extent on factors peculiar to the prime contractor, and we are content to leave these costs unestimated until a program has advanced far enough for the contractor to provide his estimate of these costs. Facility costs are highly program specific and are likewise omitted. WRM spares requirements are determined by AFLC through a process that differs to a significant degree from the process used for peacetime requirements. It was not feasible to devote additional resources to the development of an approximation of this process for MACO. The cost of WRM munitions is neither large enough nor sufficiently sensitive to system characteristics to warrant attention at this time. It should be included in a final version of an improved model, but a meaningful estimating technique has not yet been developed. Depot Supply and Second Destination Transportation costs are only indirectly attributable to individual weapon systems. The relationships are tenuous enough that little is lost by omitting them until a better understanding of the material management and distribution functions is gained through future research. Support Equipment acquisition cost is not dealt with adequately in MACO. The cost of common support equipment is estimated as a function of flyaway cost, based on a relationship documented by AFLC. This is insensitive to support concepts and, at best, only indirectly sensitive to reliability and maintainability characteristics of the weapon system. Peculiar support equipment cost is computed only as the product of quantities and unit prices, which will not be available until late in system development. Attention needs to be directed at developing a methodology that estimates support equipment cost with sensitivity to deployment and basing policies; the different requirements of flightline, shop, and depot maintenance under varying maintenance concepts; and the unique aspects of both common and peculiar support equipment.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

PROGRESS ACHIEVED AND LIMITATIONS OF MACO

We believe that MACO is a useful step toward the development of a much more satisfactory model for estimating aircraft system ownership cost. Notwithstanding its status as an interim model, MACO shows progress in overcoming several deficiencies that we noted earlier in existing ownership cost models, namely:

MACO demonstrates an estimating approach that combines the depth of detail needed for sensitivity to aircraft design characteristics with the breadth needed to generate estimates of total incremental cost.

MACO uses a set of cost elements that are internally consistent and responsive to the requirements of the OSD CAIG, and are defined in terms of Air Force programming, budgeting, and accounting categories.

Algorithms are provided for the resource categories of base maintenance manpower, depot maintenance, and recoverable spares that are (1) sensitive to a wide range of logistics support, deployment and policy-related cost-driving variables; (2) generally indicative of what is known about the causal relationships that underlie the demand for resources in these categories; and (3) consistent with the associated Air Force processes for resource allocation.

Gains have also been made in other areas of MACO: a clearer separation of intermediate resource demands (e.g., maintenance manhours) and final resource demands (e.g., maintenance manpower); time phasing capabilities for both inputs and outputs; and some flexibility in the levels of input detail, especially for base maintenance manpower and depot maintenance.

There are some important limitations to the usefulness of MACO, however. One is that the model has not been validated. Although we believe the model's algorithms to be quite reasonable approximations of the actual processes and resource demand functions they represent, there has been no full scale test of MACO—that is, the model has not been operated from initial inputs to final outputs with a comparison of the latter to known values. Although we expect that MACO could be used to generate acceptable estimates of ownership cost, we can offer no demonstration of its aggregate validity. Its main utility, at this point, is as a demonstration of a new estimating approach and as a framework for future research. Several other limitations of MACO are limitations in the state of the art for estimating and accounting for ownership costs. They are discussed in the context of recommendations for future research and suggested design objectives for future cost of ownership models.

RECOMMENDATIONS FOR FUTURE RESEARCH

Our recommendations for advancing beyond the capabilities offered by MACO emphasize three subjects: (1) increasing the comparability of estimates from one cost element to the next; (2) improving algorithms for several cost elements that are more realistic representations of the underlying cost drivers and causal relationships; and (3) creating an integrated data base for the separate elements of maintenance and maintenance-related activities and their resource demands and costs.

Comparability of Cost Elements

One of the deficiencies noted in our review of existing life cycle cost models is the inconsistent treatment and definition of individual cost elements. These inconsistencies make it difficult to assure that a dollar's worth of one resource (cost element) is equivalent to a dollar's worth of another resource. The cost elements used in MACO are helpful in this regard, but some inconsistencies remain. The MACO cost elements do not reflect weapon system influences on the Air Force budget to an equal degree. It is probably true, for example, that each aircraft weapon system has some marginal influence on the total requirement for depot supply activities. But the nature and extent of that influence is not fully understood and MACO therefore does not include a method for estimating the cost element Depot Supply. The portion of the total cost of replenishment spares that supports a given weapon system in a given year is determined by the supply system's response to item demands received from all systems, because spares are managed by item rather than by weapon system. The replenishment spares methodology in MACO does not account for this aspect of reality.

The MACO estimating procedure for replenishment spares provides a measure of the cost of resources demanded by a given weapon system; nevertheless the cost element Replenishment Spares is not fully comparable, for example, to aircrew costs. Weapon system resource demand for aircrew pay and allowances is directly reflected in budget dollars. Depot Supply and Replenishment Spares are typical of a number of cost elements that cannot be fully accommodated in a compatible manner without further research.

Our previous report[1] describes various problems that prevent one from reconciling the cost actors used in CACE with budget costs that are displayed in the F&FP for a number of cost lements, including modifications, POL, and training ordnance. Such problems should be the subject of future research aimed at identifying actual cost drivers and causal relationships.

It is also important that consistency be maintained between the cost elements of future LCC models and the categories of the Air Force programming, budgeting, and accounting systems and the CAIG guidelines for aircraft systems.

Improved Estimating Algorithms

A primary objective in future research on ownership costs should be to increase the fidelity with which individual estimating methods and algorithms represent actual causal relationships and resource allocation procedures. MACO provides algorithms for base maintenance manpower, depot maintenance and recoverable spares that are more "realistic" than those they replaced in LSC and BACE/CACE. However, similar improvements are needed for many other cost elements, including six called for by the CAIG that are omitted entirely from MACO.[2] Among the cost elements of MACO that need particular attention are those related to support equipment (SE), training, and spare engines.

The MACO algorithms for SE are simple functions of the flyaway cost of the aircraft being

[1]Marks, Massey, and Bradley, Appendix B.

[2]Training Equipment and Services, Documentation, Facilities, WRM, Depot Supply, and Second Destination Transportation.

analyzed. This approach provides no direct sensitivity or any causal or policy-related variables. Both common and peculiar SE quantities should be related to some availability or other effectiveness criterion through an analysis of demands for specific types of equipment. The analysis should consider the frequency of demands and the length of the usage periods. Sources of data with which to develop appropriate relationships may be difficult to locate.

The training cost algorithms in MACO, adopted from the CACE model, are poor and incomplete representations of the probable cost implications of a new aircraft system. More attention should be given to the initial, system-specific training provided by contractors. These are difficult costs to estimate, but one important factor is the size of the cadre of Air Force personnel that receive initial training. The cadre is typically smaller than the total number of personnel to be trained for the entire force of the new system. Algorithms are also needed for the cost of training equipment.

We have used the spare engine methods of the LSC model for MACO. The LSC methods are good representations of the AFLC requirements computation for engines managed as whole items. Modular engines, however, are managed with the help of the MOD-METRIC[3] optimization model. The MACO spare engine algorithms should be modified to include, as required, the MOD-METRIC computations.

The LSC model also has provisions for two cost elements omitted from MACO. The LSC model computes a transportation cost similar to Second Destination Transportation and costs that are elements of Depot Supply. The connections between these estimates in LSC and the actual demand for budgetary resources is not apparent, however. These cost elements probably require more thorough research before they can usefully be included in future ownership cost models. This same proviso applies to the other cost elements called for by the CAIG but omitted from MACO.

In addition to providing explicitly for policies related to ownership of individual weapon systems, future models should also take account of force-wide policies and constraints that influence the manpower levels, training requirements, and deployment plans for individual systems. Manpower costs, for example, are constrained by Congressional manpower ceilings and distribution requirements and by the skill levels available in the Air Force's labor pool. Budgeting processes that set the funding levels available to the service are often insensitive to individual weapon system requirements. Funding for depot supply and some other central support cost elements appear to be on a force-wide level of effort basis.

Finally, we believe that further improvements in estimating methods and algorithms should include measures of system effectiveness, as well as resource demands. MACO estimates only one of the elements of system effectiveness. A model that fully deserved the label "realistic" would account not only for supply support effectiveness but for other contributions to system effectiveness as well. At a minimum, total aircraft nonavailable time should be evaluated by summing the aircraft downtimes due to maintenance and lack of parts. A more satisfactory approach would be to relate resource quantities to an operating unit's achievable sortie rate.

Integration of Maintenance-Related Data Bases

One of the limiting factors in MACO, and one that more generally affects the development of improved estimating algorithms, is the lack of an integrated historical data base for compo-

[3] Air Force Logistics Command, *Recoverable Inventory Control Using MOD-METRIC*, AFLCP 57-13, February 28, 1975.

nent level maintenance and related activities. Conceptually, this need not be a problem for a totally new aircraft design, because all needed inputs could be estimated directly for each component. As a practical matter, however, most estimating problems require extensive reference to past experience. An analyst who wishes to use MACO with historical component data, either to analyze the costs of an existing aircraft or because an existing aircraft closely resembles a new aircraft design of interest, will find that the structure of the model does not directly match the structure of the relevant Air Force data systems. MACO uses a single set of component data for computations of the costs of base level maintenance, depot level maintenance, and spares. Historical reliability and maintainability information related to base level maintenance is reported by work unit code. Depot maintenance and recoverable spares information is reported by stock number. Unfortunately, there is no standard reference that relates work unit codes and stock numbers. The relationships can be developed for a given point in time by identifying the individual components associated with each work unit code and stock number, but aircraft configuration changes and other modifications would make frequent extensive revisions necessary if the information were to be kept current. The user who plans to use standard Air Force data sources should expect to do a lot of work if he wishes to assemble a set of input data that uses all the detail the model can handle.

The equations in MACO for Base Level Maintenance Manpower were based on data, standards, and LCOM simulations for TAC aircraft. The Wing Operations manpower figures presented in Section IV are also based on data for tactical aircraft organizations. Expansion of the data base to include other types of aircraft and missions is needed.

The lack of an integrated data base also adversely affects the development of improved estimating algorithms for maintenance-related estimating activities, because there is no means for assessing comparability among them. Similarly, analyses that involve tradeoffs among different levels of maintenance or between maintenance and spare parts are also impeded. The difference in the data systems is, of course, the result of differences in the management processes used for each of the maintenance resources. It is unrealistic to expect that these processes will be modified in the near term to rectify the disparities in component level data. The development of consistent "cross-walks" among the data systems should be a priority item in Air Force Visibility and Management of Support Costs efforts and in future ownership cost research.

CONCEPTUAL FRAMEWORK FOR THE DESIGN OF A FLEXIBLE MODEL

Throughout this report we have referred to MACO as an interim model, one that yields some improved capabilities for the present and provides a framework for future research. The latter includes a structure for the design and development of a model that not only includes more reliable algorithms but also is much more flexible in its application.

Such a model should be sensitive to the critical factors in a wide range of decisions, including hardware tradeoffs, support concept evaluations, and source selection decisions. It should be usable early in a program, before the design of the system has been specified in detail. It should also be able to handle the detailed hardware data used in tradeoff studies during Full Scale Development. Ideally, it should be able to use detailed data for part of the weapon system and a more aggregate representation of other parts that are of less interest in a particular case. Similarly, the model should have the ability to give either detailed or aggregate estimates of the significant elements of weapon system cost.

Some progress was made along these lines in MACO with the provision of aggregative algorithms for base maintenance manpower (and to a lesser degree depot maintenance) as alternatives to the algorithms driven by component level inputs. But this notion was not carried to its final form. MACO was developed with the expectation that some of its algorithms would be replaced with improved methods in the future. Each algorithm can be considered a replaceable module of the model. An extension of this approach could be a basis for the development of the type of flexible model suggested here. Replacement of the modules of that model would be tied to the requirements of the analysis being performed rather than to basic improvements in cost estimating techniques. The model would have available alternative modules for each of various combinations of aircraft subsystem and cost element. For a given combination, the user would be able to select the module that offered the level of detail most appropriate for the problem at hand. Two alternative modules would be adequate for many combinations—one using a detailed approach based on the characteristics of individual hardware components, such as aircraft shop replaceable assemblies, and a second using a more aggregate approach. The level of aggregation for the aggregate model modules might range from the two-digit work unit code level to a level comparable to that of the cost factors provided in AFP 173-13.

Issues that arise early in weapon system development would usually be addressed with aggregate model modules exclusively. As development progresses, detailed data become available; and many decisions require a more detailed examination of some hardware components and cost elements than others. The selection of a preferred landing gear design, for example, must consider design details for the landing gear but not for the rest of the aircraft. Most of the weapon system could be treated with aggregate modules. Similarly, not all cost elements are equally significant for all decisions. An analysis in support of a source selection decision should give equal emphasis to all costs that differ between the competing contractors. This could require estimation of all elements of the cost of ownership, perhaps at an aggregate level. Landing gear tradeoff studies, however, could concentrate on costs related to maintenance and spares support, because these costs would probably be affected by the choice of design. The flexible model should be constructed so that all costs related to landing gear design (including the various costs of supporting maintenance personnel) would be captured by a few components. Most of the model (most of its modules) used in such design tradeoffs could be those using aggregate algorithms. Source selection and design tradeoffs, as well as other decisions associated with system development, could be addressed by a single flexible model if enough interchangeable modules could be developed.

The development of the base level maintenance manpower algorithms used in MACO illustrates how the modules of the flexible model might be developed. The basic MACO approach separately treats the manpower for individual work centers, building up the workload for each work center from the characteristics of the individual aircraft hardware components. This is significant in two respects. First, the representation of the flow of hardware components through the various maintenance activities provides a realistic link between computed manpower and input hardware characteristics. Second, the structure of work centers and related hardware components could be used as part of a definition of suitable modules for the flexible model. A complete operational definition would of course have to address the specific problems associated with hardware that is maintained by more than one work center.

MACO already offers an alternative aggregate method for base level maintenance manpower. Section III of this report shows how manhour (or manhour per flying hour) data at the two-digit work unit code level can be distributed over the various work centers. This allows the estimation of manpower by work center without the need for detailed hardware characteristics. This use of a single framework for both detailed and aggregated methods would be a basic feature of a flexible model. Design and development of such a model would contribute significantly to helping life cycle analysis reach its full potential in the Air Force system acquisition management process.

GLOSSARY

AFIF	Air Force Industrial Fund
AFLC	Air Force Logistics Command
AFR	Air Force Reserve
AGE	Aerospace Ground Equipment
AGM	Air-to-Ground Missile
AGMC	Aerospace Guidance and Metrology Center
AGS	Aircraft Generating Squadron
AIM	Airborne Interceptor Missile
ALC	Air Logistics Center
ANG	Air National Guard
ASIF	Airlift Services Industrial Fund
ATBO	Average Time Between Overhauls
BACE	The Planning, Programming and *B*udgeting *A*nnual *C*ost *E*stimating model
BOS	Base Operations Support
CACE	The *C*ost *A*nalysis *C*ost *E*stimating model
CAIG	OSD Cost Analysis Improvement Group
CCT	Combat Crew Training
CILC	Centralized Intermediate Logistics Concept
CONUS	Continental United States
DAPCA	A Rand model for development and procurement cost of aircraft
DLH	Direct Labor Hours
DMS	Depot Maintenance Service
DSARC	Defense Systems Acquisition Review Council
ECM	Electronic Countermeasures
EMS	Equipment Maintenance Squadron
EOH	Engine Overhaul
EOQ	Economic Order Quantity
FAC	Functional Account Code
FY	Fiscal Year
F&FP	The USAF Force and Financial Plan
GFAE	Government Furnished Aeronautical Equipment
GFM	Government Furnished Material
G&A	General and Administrative
IM	Item Manager
LCC	Life Cycle Cost
LCOM	Logistics Composite Model
LRU	Line Replaceable Unit
LSC	Logistics Support Cost Model
MANPOWER	A computer program developed to estimate USAF aircraft maintenance manpower requirements
MDS	Mission/Design/Series
MFP	Major Force Program

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MTBF	Mean Time Between Failures
MTBO	Maximum Time Between Overhauls
NDI	Non-Destructive Inspection
NORS	Not Operationally Ready—Supply
NRTS	Not Reparable This Station
OFM	Organizational and Field Maintenance
OSD	Office of the Secretary of Defense
O&M	Operations and Maintenance
PAA	Primary Aircraft Authorization
PACAF	Pacific Air Force
PA&E	Program Analysis and Evaluation
PCS	Permanent Change of Station
PDM	Programmed Depot Maintenance
PMEL	Precision Measuring Equipment Laboratory
PE	Program Element
POL	Petroleum-Oil-Lubricants
POMO	Production Oriented Maintenance Organization
PPE	Primary Program Element
RPM	Real Property Maintenance
PRICE	An RCA proprietary model for avionics development and procurement costs
R&D	Research and Development
SE	Support Equipment
SM	System Manager
SRA	Specialized Repair Activity
SRU	Shop Replaceable Unit
TAC	Tactical Air Command
TBO	Time Between Overhauls
TDY	Temporary Duty
UE	Unit Equipment (now termed Primary Aircraft Authorization, PAA)
USAFE	United States Air Forces—Europe
VAMOSC	Visibility and Management of Support Costs
VSL	Variable Stock Level
WRM	War Readiness Material
WUC	Work Unit Code

Appendix A

USAF PROGRAM ELEMENTS, APPROPRIATIONS, AND LIFE CYCLE COST ELEMENT DEFINITIONS

This appendix presents the full definitions of the cost elements used in developing MACO. The current CAIG cost element structure should be used in any operating version of MACO. Appendix D shows how MACO cost elements could be translated into the most recent (April 1980) CAIG O&S cost element definitions.

At the highest level of aggregation, the costs that are of concern in life cycle analysis are the incremental USAF budget costs incurred as a consequence of adding an aircraft system to the force and operating it over a period of time. We specify *USAF budget costs* because we are primarily interested in what funds the Air Force will have to spend if a specific course of action is taken. We specify *incremental* costs because we are interested in the costs that can be expected to arise as a consequence of the decision (rather than a cost accounting concept, which would include allocated overhead costs that normally would not be affected by the decision). To define incremental costs clearly, it is necessary to establish a common understanding of the baseline from which the incremental costs are calculated. The baseline is usually the currently planned force. In most cases the new weapon system is a modest addition to the total force, or it is intended as a replacement for an existing system. Under these conditions the incremental costs will consist of the direct costs of the system and its major variable indirect support costs (marginal changes in base operations, central training, supply, and other such support costs). The fixed costs of opening bases, operating the Air Force Logistics Command and Air Training Command, etc. would be unaffected by the weapon system decision. Occasionally a case may arise where some of the "fixed" costs are also sensitive to the weapon system decision (a system using a new basing concept might require an expansion, or permit a reduction, in "fixed" base facilities). The framework of LCC categories described below applies primarily to the usual variable costs. Cases involving changes in forcewide basing or support structure may require some additional cost elements to capture the costs of making those changes.

USAF PROGRAM STRUCTURE

The *USAF Force and Financial Program* (F&FP) divides Air Force activities and organizational units, manpower authorizations, and budget costs into ten Major Force Programs (MFPs) with Program Elements (PEs) within the MFPs. Associated with each PE are specific equipment, facilities, manpower, and costs. The costs are divided into appropriation categories and cost elements (CEs) within appropriations. In many cases we can define life cycle cost elements for aircraft systems directly in terms of F&FP PEs. This can be done readily for the direct costs of weapon systems; but for indirect support costs, PE definitions alone are not sufficient to define the costs attributable to a specific system. It is possible, however, to specify the PEs that cover forcewide total costs in each support category. The task of identifying the fixed and variable components of cost within each support cost category was not undertaken here, as it is more appropriately considered after the composition of the categories is formally established.

Table A.1 presents a list of program element categories (with examples of specific PEs) that can be matched with certain individual LCC elements or subsets of LCC elements. The PEs listed here and the comments presented below are based on the F&FP of February 1978. Changes are made to this structure from t me to time; hence adjustments to the PE categories may occasionally be required to bring them into conformity with the latest program structure.

Primary Program Element and Combat Crew Training

The first category in the table covers the primary direct costs of a weapon system. The Primary Program Element (PPE) covers procurement costs and the direct (base level) operating costs of deployed units. Development costs may be identified with the PPE (for systems approved for production) or in a separate PE in MFP 6—Research and Development (for systems not yet approved for production). Aircrew training or Combat Crew Training (CCT) operations may be funded in the PPE or in a separate Training PE in the same MFP. The example training PEs listed under this category (27597 and 41897) include CCT units for the major aircraft systems contained in their Major Force Programs. Procurement costs of CCT aircraft are usually assigned to the PPE, rather than to the CCT PE. Taken together, the costs funded in PPE and CCT categories for a given aircraft system should equate with the life cycle cost elements: Research and Development, Investment (except, possibly, for part of War Reserve Material costs), Deployed Unit Operations, Below Depot Maintenance, and Sustaining Investments (except for Training Ordnance).

Depot Maintenance

Although we have categorized depot maintenance costs as "direct weapon system costs" in Table A.1, these costs are not included in PPE or CCT program elements for most aircraft.[1] Depot maintenance costs for all active USAF aircraft—excluding Air Force Reserve (USAFR), Air National Guard (ANG), and Airlift Service Industrial Fund (ASIF) aircraft—are contained in PE 72207-Depot Maintenance Activities (Non-IF). In order to obtain information on the depot maintenance costs for individual aircraft systems one must turn to separate depot cost reports. The funding for an aircraft system's depot maintenance would normally be wholly contained within PE 72207, although the personnel who perform depot maintenance work are shown elsewhere in the F&FP—in PE 72007-Depot Maintenance Activities (IF). We must defer explanation of this apparent contradiction until we describe the appropriation breakdown of costs in the F&FP.

Indirect General Support Costs

The remaining PE categories in Table A.1 cover the costs that should be included in the life cycle cost elements: Installations Support, Depot Supply, Second Destination Transportation, Personnel Training and Support, and Training Ordnance. A portion of the War Reserve Material (Support Investment) cost element may also be covered in the last PE category in our

[1] The exceptions to this rule are the industrially funded airlift aircraft. PPE costs for these aircraft do include depot maintenance costs.

Table A.1

PROGRAM ELEMENT CATEGORIES AND EXAMPLE PEs

DIRECT WEAPON SYSTEM COSTS
- Primary Program Element (PPE) and Combat Crew Training (CCT)
  - 27130--F-15 Squadrons
  - 27133--F-16 Squadrons
  - 41313--Advanced Medium STOL Transport (AMST)
  - 27597--Training-Tactical Air Forces
  - 41897--Training-Airlift Forces
  - 64228--AMST Development (R&D costs only)
  - 64229--F-16 Development (R&D costs only)
- Depot Maintenance
  - 72007--Depot Maintenance Activities (IF)
  - 72207--Depot Maintenance Activities (Non-IF)

INDIRECT GENERAL SUPPORT COSTS
- Installations Support
  - 11894--Real Property Maintenance Activities (RPMA)-SAC
  - 11895--Command and Base Communications-SAC
  - 11896--Base Operations-SAC
  - 27594--Real Property Maintenance Activities-Tactical Forces
  - 27595--Command and Base Communications-Tactical Forces
  - 27596--Base Operations-Tactical Forces
- Depot Supply
  - 71111--Supply Depots/Operations (Non-IF)
  - 71112--Inventory Control Point Operations
  - 71113--Procurement Operations
- Second Destination Transportation
  - 78010--Second Destination Transportation
- Recruiting and Individual Training
  - 81711--Recruiting Activities
  - 81712--Advertising Activities
  - 81713--Examining Activities
  - 81714--Personnel Processing Activities
  - 84711--Recruit Training Units
  - 84721--Service Academy
  - 84722--Officer Candidate/Training Schools (OCS)
  - 84723--Reserve Officer Training Corps (ROTC)
  - 84724--Other College Commissioning Programs
  - 84731--General Skill Training
  - 84741--Undergraduate Pilot Training
  - 84742--Undergraduate Navigator/NFO Training
  - 84751--Professional Military Education
  - 84752--Other Professional Education
- Health Care
  - 87711--Care in Defense Facilities
  - 87713--Care in Nondefense Facilities
  - 87714--Other Health Activities
- PCS Travel
  - 88731--Permanent Change of Station
- Training Munitions and General WRM Equipment
  - 27161--Tactical AIM Missiles
  - 27162--Tactical AGM Missiles
  - 27599--Munitions Training Items
  - 28030--WRM-Ammunition
  - 28031--WRM-Equipment/Secondary Items

list (Training Munitions and General WRM). These are called indirect, general support costs, because the services and materials they cover are used jointly by many weapon systems and other Air Force activities. The PEs contained in each category should be used as the means of identifying forcewide total costs in these categories. The definitions shown here appear to us to be the most suitable for life cycle analysis, but they are not the only possible definitions. It is important to establish standard definitions, so that one can see where an LCC estimate fits in relation to total USAF resources, but the definitions eventually adopted by the Air Force need not be exactly the same as those presented here.

Because the general support costs are indirect and jointly shared by many weapon systems (and other Air Force activities), there is no way of identifying the "correct" general support cost attributable to a single weapon system. Some services in this category may be identified with a single system (e.g., a technical training course that pertains to skills required by only one system), but most general support services apply to items common to several systems or to personnel categories that are common to many different organizations. Not all of the cost of providing support services is sensitive to weapon system or force level decisions; there is a startup cost. The usual approach to this problem is to use conventions to estimate the marginal effect on a system category of a change in direct weapon system requirements (e.g., marginal change in training costs as a function of the number of direct personnel). This report does not define these conventions explicitly, but they are an essential part of a complete and consistent framework for life cycle cost estimation.

The *Installations Support* category in Table A.1 includes a representative set of PEs for this category. The costs covered here are for base support activities, including Civil Engineering, Transportation, Services, Accounting, Personnel, and Communications. On each Air Force base these activities are funded by a single "host" command and are provided to all tenants on the base. The base support activities on all bases for a particular command are summed into a single set of Installations Support PEs. For example, PEs 27594 through 27596 cover the RPMA, Communications, and Base Operations costs for bases operated by Tactical Air Command (TAC), Pacific Air Forces (PACAF), and U.S. Air Forces in Europe (USAFE). A complete list of the relevant PEs for this category would include Real Property Maintenance Activities, Base Communications, and Base Operations PEs for all MFPs.[2] Only a portion of these costs is sensitive to changes in weapon systems and force levels, and there is no direct means of identifying the specific Installations Support cost associated with a single system. Thus conventions must be adopted to define weapon system costs in this category.

The PEs listed under the Depot Supply and Second Destination Transportation categories in Table A.1 appear to be the appropriate ones for these costs as defined in the CAIG Guide. As with Installations Support costs, there is no way to identify these costs uniquely to specific weapon systems. Furthermore, no generally accepted conventions have been devised for this category.[3] Thus, although the PEs can be used to define forcewide costs, there is no present capability to assess the accuracy of a given technique for estimating weapon system costs in these areas. Historical trends and future years' projections in the F&FP suggest that overall

[2]These appear explicitly in MFPs 1-5 and 7-9. AFSC base support costs are included in MFP 6, but there are no PEs with these titles in MFP 6. Alternative "Base Operating Support" definitions have been proposed that include PE 33112—Air Force Communications—and PE 35114—Traffic Control, Approach, and Landing System. Although it is not unreasonable to include these PEs in the Installations Support category, their costs do not appear to be particularly sensitive to weapon system decisions, and we have omitted them. Whatever definition is used, it should be applied consistently across all types of bases and across all types of tenants supported by these activities.

[3]The Air Force operating cost reporting system for aircraft (VAMOSC-AIRCRAFT) uses allocation rules to identify some portion of these costs to weapon systems. However, there is apparently no connection between these allocation rules and the programming/budgeting procedures used to establish forcewide resource requirements in this category.

budgets for these activities are set at a policy-directed level of effort and are quite insensitive to changes in weapon system characteristics and force levels.

The categories we have called Recruiting and Individual Training, Health Care, and PCS Travel are roughly equivalent to the CAIG Guide category called Personnel Training and Support. The PEs listed in these categories cover forcewide activities that either support Air Force personnel directly (e.g., Health Care) or are required to provide appropriate general training and career progression (including rotation of personnel through different duty assignments). As with other support cost categories, only a portion of these costs is sensitive to changes in weapon system manpower requirements, and conventions must be established to identify the costs attributable to a weapon system.

The Training Munitions and General WRM Equipment category in Table A.1 includes the PEs that cover the costs of items consumed in peacetime training activities and those stocked for use in wartime. Annual budgets for these items are established by a complex combination of training standards, wartime scenarios, and budgetary constraints. It is difficult to trace these costs to specific weapon systems without including the other factors as well, and it is thus necessary to establish conventions rather than direct relationships to identify a weapon system's share of the costs in this category.

APPROPRIATIONS AND APPROPRIATION COST ELEMENTS

The appropriation/CE breakdown of costs within a program element can be used to identify the specific set of costs in the F&FP that should be associated with each life cycle cost element. Table A.2 lists the appropriations and CEs used in the LCC element definitions that are presented later in this appendix. This list does not show all cost categories that appear in the F&FP, only those that are essential to the LCC element definitions.

One major reason for the importance of the appropriation structure in viewing cost estimates is that it is an important facet of the accounting and control of expenditures in the Air Force. The F&FP program element structure is used directly in budgeting and accounting for costs in the operating cost appropriations. Thus it is possible to estimate, budget, and account for costs in similar categories where the LCC structure and program structure coincide (i.e., for direct weapon system operating costs). In addition to this, operating cost data that are directly relevant to some LCC categories can be collected from existing accounting systems.

In contrast to the operating appropriations, the development and investment appropriations are only partly tied to weapon systems and the F&FP program structure. Within these appropriations, budgeting and accounting are oriented toward equipment end-items. It is fairly easy to identify direct system development and investment costs (because the end-items are directly associated with the weapon system), but other initial and sustaining investment costs (e.g., Common Aerospace Ground Equipment (AGE), Spares, War Consumables, etc.), are associated with end-items that may be common to many systems. The "cost" of replenishment spares as stated in the F&FP for a weapon system PPE only represents an estimate of the system's share of forcewide replenishment spares. The only way to tie actual expenditures back to weapon systems (or to PEs) is to identify all items purchased and the system(s) against which each type of item should be charged. This is a massive task, and even if it were routinely done, it still would involve somewhat arbitrary assignment of some costs. The dimensions of this problem are difficult to estimate, because the peculiar/common breakdown varies both by weapon system and by type of end-item (e.g., a large fraction of avionics equipment for current aircraft is "common," but a new system might use many new, peculiar avionics subsystems).

Table A.2

APPROPRIATIONS AND KEY COST ELEMENTS FOR LCC ELEMENT DEFINITIONS

Development Appropriation
  3600--Research, Development, Test and Evaluation (RDT&E)

Investment Appropriations
  3010--Aircraft Procurement
    Aeronautical Vehicle
    Peculiar Support
    Prior Year Credit
    Advance Buy
    Weapon System Initial Spares
    Modifications
    Modification Initial Spares
    Component Improvement
    Common AGE[a] (costing)
    Common AGE (new acquisition)
    Common AGE (simulators)
    Common AGE Spares
    Replenishment Spares (costing)
    Replenishment Spares (WRM)
    War Consumables
    Other Charges
    First Destination Transportation
  3020--Missile Procurement
  3080--Other Procurement
    Munitions and Associated Equipment
    Vehicular Equipment
    Electronics and Telecommunications
    Other Base Maintenance and Support Equipment
  3300--Military Construction

Operating Appropriations
  3400--Operations and Maintenance (O&M)
    Civilian Personnel
    Travel of Personnel
    Transportation of Things
    Standard Level User Charges
    Other Utilities and Rents
    Communications
    Printing and Reproduction
    Payments to Foreign Indirect Hire Personnel
    Purchased Equipment Maintenance-Comm.
    Purchased Equipment Maintenance-DMIF
    Purchased Equipment Maintenance-Other
    Other Purchases from Industrial Funds
    Other Purchased Services
    Aircraft POL
    Other Supplies
    Equipment
    Other Expenses

Table A.2—continued

3500--Military Personnel	
	Air Force Personnel-Officers
	Air Force Personnel-Airmen
	Air Force Personnel-Cadets
	Permanent Change of Station Travel
4922--Air Force Industrial Fund	
	Depot Maintenance (DMIF)
	Airlift Service (ASIF)
	POL
	Depot Maintenance
	Civilian Personnel
	Other Expenses

[a] The term "AGE" is being replaced by the term "Ground Support Equipment" (GSE). We have retained the term AGE, as this is still the term that appears in the F&FP.

The Air Force Industrial Fund (AFIF) is a revolving fund (not an appropriation), which is not included as part of the Air Force's regular budget (total obligational authority). Costs shown under the AFIF cover activities or services performed by the Air Force for various "customers" (some of whom are other Air Force organizations) who reimburse the Air Force out of their own budgets. The Depot Maintenance Industrial Fund (DMIF) portion of the fund covers the cost of personnel, expense material and contractual services for depot maintenance activities. Depot maintenance costs for all active USAF aircraft are reimbursed to the fund from the USAF Operations and Maintenance (3400) appropriation. These O&M costs are shown as a total (not broken down by aircraft system) in PE 72207—Depot Maintenance Activities (Non-IF). Total 4922-DMIF costs (including active USAF, USAFR, ANG, Airlift-IF aircraft, and non-AF customers) are recorded in the F&FP in PE 72007—Depot Maintenance Activities (IF). Pay and allowances for the civilian manpower authorizations associated with PE 72007 are included in the 4922 funding total for this PE instead of in the O&M appropriation.

The Airlift Service Industrial Fund (ASIF) portion of the Industrial Fund provides for reimbursement of costs incurred by USAF airlift aircraft in carrying passengers and cargo for various customers (including other Air Force organizations). For analytical purposes the ASIF can be thought of as a substitute for the O&M appropriation for airlift aircraft.[4] Depot maintenance costs for these aircraft are included (under ASIF) in each airlift aircraft PPE instead of in PE 72207—Depot Maintenance Activities (Non-IF).

DEFINITIONS OF USAF AIRCRAFT LIFE CYCLE COST ELEMENTS

The definitions presented here for the life cycle cost elements are based on the definitions given in the CAIG Guide, with the addition of information from the program and budget structure as discussed above.

[4] However, CCT units for airlift aircraft are funded under the O&M appropriation.

Research and Development

This category includes all costs of research and development activities conducted to prepare for weapon system production—the cost of Air Force technical and management activities and the cost to the Air Force of contractor studies. Costs incurred before production approval appear in the F&FP in MFP 6. After production is approved, costs appear in the PPE with which the operating system is identified.

System Investment

System investment includes the flyaway cost (procurement cost) of the Aeronautical Vehicle, as defined in the F&FP, and all other costs of producing or procuring the aircraft (including in-flight hardware and software), managing the acquisition program, and delivering the aircraft to operational units. Included in these other costs are costs associated with the Component Improvement, Other Charges, and First Destination Transportation elements of the Aircraft Procurement appropriation. The Component Improvement Program funds GFAE improvements (primarily turbine engines) during aircraft production. Other Charges include stock fund fuel (for use by the contractor for testing and for initial fill of aircraft before flyaway). It also includes the cost of ECM pods and alternate mission equipment (airborne photography, reconnaissance, etc.) used on the aircraft. First Destination Transportation is the cost of initial shipment of goods to the Air Force. The Prior Year Credit and Advance Buy cost elements included in the list in Table 5 (Section II) are time-phasing adjustments to the Air Vehicle cost to account for one-year advance funding requirements for long lead-time items.

The cost of managing the acquisition program includes the cost of operating the System Program Office (SPO). This cost is largely independent of weapon configuration,[5] hence it can be omitted when examining alternatives within a single aircraft development program. However, an acquisition program that is substantially larger or more complex than another will probably have a larger and more costly SPO.

Support Investment

Almost all Support Investment is associated with the PPE; exceptions are noted in the individual cost category definitions below.

Support Equipment. This category includes the cost of acquiring the initial inventory of support equipment and software, both common and peculiar, needed to operate or support aircraft and aircraft subsystems and support equipment: (1) peculiar support equipment identified with the weapon system and considered part of the weapon system cost, which is accounted for in the Peculiar Support cost element of Aircraft Procurement; and (2) in-service support equipment common to more than one type of aircraft, which is accounted for in the Common AGE (Aerospace Ground Equipment) cost element of Aircraft Procurement. Replacement support equipment costs funded as either Common AGE or Peculiar Support are excluded (see Replenishment Ground Support Equipment).

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[5]All SPOs and other acquisition management activities of the Aeronautical Systems Division of the Air Force Systems Command are funded, generally at an overall level of effort, under PE 65806—Acquisition and Command Support.

Training Equipment and Services. This category includes the cost of acquiring and installing initial training equipment, including weapon system peculiar simulators, and the cost of initial training services. Initial training services includes the cost of factory training provided by contractors at their facilities to qualify an initial cadre of skilled personnel to operate and maintain the equipment and initially man Air Force weapon system-related courses.[6] Excluded are trainee pay and allowances and travel costs (see Individual Training).

The cost of initial training services is, in part, a function of the weapon system's manpower requirements, but for analytic purposes, the determination of system manpower requirements is considered under a separate category (see Deployed Unit Operations and Below Depot Maintenance).

These costs are funded under the Aircraft Procurement appropriation. Most are included in the Peculiar Support cost element.

Documentation. This includes the cost of gathering, storing, reproducing, and disseminating technical data describing the weapon system and data needed for program management and the cost of preparing, updating, and reproducing publications such as technical manuals needed to operate and maintain the system. These materials are normally furnished by the contractor and are funded under the Peculiar Support cost element of Aircraft Procurement.

Documentation and updating costs after production is complete are O&S costs and are excluded from this category (see Technical Support).

Initial Spares and Repair Parts. The cost of procuring aircraft, AGE, and training device spares and repair parts that are:

1. Investment items (Reparable items that are centrally managed with individual item reporting—per AFR 170-14), and
2. Support for new aircraft for an initial period of operations, normally not more than two years. (This is a definition by convention; an analysis should assess total spares—initial plus replenishment.)

These spares are funded by the Weapon System Initial Spares and Common AGE Spares cost elements of the Aircraft Procurement appropriation. Some items may be funded by the Other Charges cost element.

Spare Engines. The cost of spare engines and spare engine module components to support the wartime flying program, including war reserve requirements. These spares are funded by the Weapon System Initial Spares cost element of the Aircraft Procurement appropriation.

Facilities (Non-production). The cost of construction, conversion, or expansion of government facilities for operation and support of the weapon system. This work is usually accounted for under the Military Construction appropriation. Facilities projects costing no more than $75,000 may be funded under the Other Purchased Services cost element of the O&M appropriation.

War Reserve Material (WRM). The cost of establishing or increasing stocks to support wartime requirements.

Spares and Repair Parts. These are funded in Aircraft Procurement, under Replenishment Spares (WRM) and Weapon System Initial Spares.

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[6]This cost element does not include general recruiting and training costs for the "first set" of personnel for the full force. Such costs are assumed to be included (when time phasing is done properly) in the O&S cost category Individual Training and in CCT operating costs.

Munitions. These are provided for in program element 28030, WRM Ammunition, and funded in the Other Procurement appropriation.

Missiles. These are funded in the Missile Procurement appropriation and identified with program elements 27161, Tactical AIM Missiles, and 27162, Tactical AGM Missiles. Some large or expensive airborne missiles (e.g., Maverick, SRAM) are funded in separate program elements of their own. If an aircraft system generates requirements for increased war reserve stocks for these missiles, the costs would appear in the individual PEs rather than in the Tactical AIM and AGM PEs listed above.

Tanks, Racks, Adapters & Pylons. These items of equipment are stocked to replace items that would be expected to be consumed in wartime operations. The cost is provided for under the War Consumables cost element of Aircraft Procurement. The cost of ECM pods and alternate mission equipment stocked for wartime use would be included in the Other Charges cost element of Aircraft Procurement.

Wing Operations

A deployed unit is any unit (wing, aircraft squadron, etc.) operating in the field for combat, training (CCT), or any other operating purpose. In the F&FP and in the Base Operating Budget Status Report, RCS HAF-ACF(Q) 7146, deployed unit costs would be charged against an aircraft squadron program element (PPE) or against a training (CCT) PE. Depending upon the purpose of the cost estimate, these costs may or may not include costs associated with support aircraft operated by the deployed unit.

Aircrews. This category includes pay and allowances[7] for all aircrew personnel required to meet combat and training requirements plus such administrative requirements as leave. Aircrews are identified with manpower and organization function codes (FC) 311x and 3718, as defined in AFM 300-4.[8] This cost is accounted for under the Military Personnel appropriation.

Command Staff. This category includes pay and allowances for all personnel required for flying supervision: command, operations control, planning and scheduling, flight safety, quality control on aircrew training and flying proficiency; includes combat and squadron commanders and their staffs. This cost is accounted for under the Military Personnel and O&M appropriations. Functional categories included are wing commander, vice commander, and executive assistant aides and secretaries (FC 1010); personnel assigned to flight safety (FC 1061); operations staff (FC 13xx less 1311 and 1330), and mission equipment personnel other than aircrews (FC 3100 or 3718, the squadron commander and operations officer; and FC 3101 or 3701, first sergeant and other squadron administration personnel).

Aircraft POL. This category includes the cost of aviation POL for support of peacetime operations, consumption in flight and on the ground plus allowance for distribution, storage, and spillage. This cost is accounted for in the Aircraft POL cost element of the O&M appropriation. POL expenditures are accounted for in the accounting system under Elements of Expense/Investment Codes (EEICs) 601, 698, and 699.[9]

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[7]The term "pay and allowances" for military personnel covers costs funded in the Military Personnel appropriation, under the cost elements "Pay and Allowances—Officers" and "Pay and Allowances—Enlisted." For civilian personnel, it covers costs funded in the Operations and Maintenance appropriation, under the cost element Civilian Personnel and Payments to Foreign Indirect Hire (FNIH) Personnel.

[8]*Data Automation Data Elements and Codes*, AF Manual 300-4, Department of the Air Force, 10 March 1976, *Vol. XII—General Purpose*, ADE FU-500

[9]AFM 300-4, *Vol. X—Comptroller*, ADE EL-191.

Security. This category includes pay and allowances for aerospace system security personnel, including both the actual security force and related administrative personnel (FC 435X, Aircraft and FC 438X, Nuclear weapon storage areas). This cost is accounted for under the Military Personnel appropriation. Civilian manpower is not usually authorized for this function.

Other Wing Manpower. This category includes pay and allowances for other personnel assigned to deployed units and charged to the appropriate PPE or CCT PE, including Information (FC 104X), Logistics (12XX), and Safety (106X) other than Flight Safety (1061). Includes student aircrew personnel assigned to combat crew training squadrons. This cost is accounted for under the Military Personnel and O&M appropriations.

Miscellaneous Operations and Main'enance. All deployed unit operating costs not accounted for by other cost elements are collected together as Miscellaneous Operations and Maintenance costs. These are funded under the Operations and Maintenance appropriation and include the costs of TDY travel, utilities, purchased services, and miscellaneous supplies and equipment. The costs may appear in any O&M cost elements except for Civilian Personnel or Aircraft POL.

This cost category is called "personnel support" in the CAIG Guide, but the term "Miscellaneous O&M" is used here to account for costs that are not necessarily personnel-related. Costs in this category are often estimated on a cost-per-man basis, but manpower requirements are estimated separately under the categories Aircrews, Command Staff, Security, and Other Deployed Manpower, described above.

Base Level Maintenance

This category includes the cost of Air Force manpower and material and contractual support for base level maintenance of aircraft, support equipment, and ordnance. These costs are associated with an aircraft squadron program element (PPE) or with a CCT program element. (For analytical purposes, contractual support costs should be divided among the appropriate manpower and material cost subcategories listed below. Contractual support costs for current systems are normally accounted for under the Purchased Equipment Maintenance cost element of Operations and Maintenance.)

Aircraft Maintenance Manpower. This category includes the cost of personnel performing maintenance and general support of assigned aircraft, support equipment, and training devices. Training devices associated with deployed units are maintained by personnel assigned to the aircraft maintenance organization but not separately identified. Aircraft maintenance activities are performed by personnel assigned to aircraft squadrons (unit aircrew life support, FC 3102), organizational maintenance squadrons (all FC 22XX except 2230, Support Equipment, and 225X, Base Flight and Transient Aircraft), field maintenance squadrons (FC 23XX except 234X, AGE), and avionics maintenance squadrons (FC 24XX except 2450, PMEL; 2461, avionics AGE; and 2470, Avionics AGE). Support equipment is maintained by the PMEL and AGE shops: 2230, 234X, 2450, 2461, and 2470. Included are the pay and allowances of personnel assigned to the Chief of Maintenance functions, as defined in AFM 66-1, to the extent these functions relate to aircraft maintenance rather than ordnance maintenance. Typically Chief of Maintenance (FC 21xx) personnel are assigned to a wing headquarters, but they may be at a lower level in small organizations.

Ordnance Maintenance Manpower. The cost of personnel performing maintenance and service functions for munitions, missiles, and related systems. These personnel are assigned to Airborne Missile Maintenance squadrons (FC 248X) or Munitions Maintenance squadrons (25XX). Included are the pay and allowances of personnel assigned to the Chief of Maintenance functions, as defined in AFM 66-1, to the extent these functions relate to ordnance maintenance rather than aircraft maintenance.

Maintenance Material. The cost of expense material used in maintenance. This includes spares and repair parts that are:

1. Nonreparable, or
2. Reparable, but not centrally managed with individual item reporting (see AFR 170-14).

This spares cost is reported in the accounting system under EEIC 605 (System Support Division, AFSF), 609 (General Support Division, AFSF), or 61X (Base Procured Non-Stock Fund Material for Direct Consumption). Also included in this element are packaged oil and lubricants, which are charged to EEIC 602 and are obtained from the General Support Division of the stock fund (AFR 173-10, Vol. II, p. 2-1). The O&M appropriation provides for this cost under the cost element Other Supplies. Additional maintenance material expenses may be incurred in EEICs 62X and 63X, which are covered in the Equipment cost element of O&M.

Miscellaneous Operations and Maintenance. All other operating costs of base level maintenance organizations not covered under the Maintenance Manpower and Maintenance Material categories above. See comments under the Miscellaneous O&M category for Deployed Unit Operations.

Installations Support

Installations Support cost is the variable cost of manpower, materials, and purchased services used in supporting the operation of Air Force bases and the tenants that occupy them. Organizationally, these activities consist primarily of those under the supervision of the Combat Support Group. They include the functions performed by the Communications Squadron, Civil Engineering Squadron, Supply Squadron, Services Squadron, Security Police Squadron (excluding weapon system security), Transportation Squadron, and that portion of the Wing Headquarters organization not charged to mission elements (accounting, personnel, etc., but not Wing commander, operations staff, or chief of maintenance). Transient aircraft maintenance, which is handled normally by the Field Maintenance Squadron, is also counted as part of Installations Support. These functions support all tenants on a base, but there is no way of identifying them uniquely to specific tenants except by the adoption of conventions for allocating their costs to the tenants. Usually it is assumed that only a portion of Installations Support cost of a base varies with the mission population (and hence is attributable to tenants). The rest of the cost is assumed to be related to characteristics of the base itself and is, therefore, "fixed" with respect to weapon system changes.

These costs are accounted for under Real Property Maintenance Activities, Base Communications, and Base Operations program elements. The materials and purchased services costs included in this category include miscellaneous O&M costs sometimes referred to as "personnel support" costs, which generally vary with the number of mission personnel supported but are not restricted to expenses that are personnel-related. Base Operating Support (BOS) and Real

Property Maintenance Activities (RPMA) costs are sometimes addressed as separate cost elements, but the factors that drive these costs are imperfectly understood. Because current techniques do not provide a very good means of separating the factors that may affect BOS and RPMA costs differently, Installations Support cost can be treated as a single category without any loss of accuracy.

Base Operations program elements generally include costs in the Military Construction and Other Procurement appropriations (the latter are primarily Vehicular Equipment and Base Maintenance and Support Equipment costs), but Air Force accounting systems do not provide a satisfactory means of tracking all expenditures in these areas back to specific bases or to systems supported on the bases. On the whole, requirements in these areas are probably not very sensitive to changes in mission population, and they can usually be omitted as a component of weapon system Installations Support costs.

Depot Maintenance

This item includes the cost of manpower, material, and contractual services needed to perform aircraft, aircraft component, and aircraft support equipment maintenance and to install modifications at DOD centralized repair depots and contractor repair facilities. Each weapon system's depot maintenance cost is accounted for as part of the total cost for the Depot Maintenance Activities (Non-IF) program element, 72207. These costs are funded by the Military Personnel and O&M appropriations. Most of the civilian personnel engaged in depot maintenance work are authorized under PE 72007—Depot Maintenance Activities (IF). They are funded under the DMIF account rather than under O&M. The Purchased Maintenance (DMIF) costs shown under PE 72207 represent reimbursements to the DMIF for depot maintenance work. Depot maintenance work performed by contractors is also funded under the DMIF appropriation. For analytical purposes, contractor costs should be separated, as are organic depot maintenance costs, into manpower and material cost elements.

Manpower. The cost of labor needed to perform major overhaul, repair, modification, inspection, and storage and disposal of aircraft and aircraft components and support equipment. Includes variable cost of overhead for organic repair.

Material. The cost of expense material consumed in depot overhaul, repair, inspection, storage, and disposal processes. This includes spares and repair parts that are:

1. Nonreparable, or
2. Reparable, but not centrally managed with individual item reporting (see AFR 170-14).

Depot Supply

This category includes the cost of manpower, material, and contractual services needed to buy, store, package, manage, and control the supplies, spares, and repair parts used in operating and maintaining aircraft and aircraft components and support equipment; it provides service engineering and technical data support for aircraft systems. These costs are funded by the Military Personnel and O&M appropriations.[10]

[10]The cost in this category represents forcewide support activities that have only recently come to be regarded as components of weapon system cost. On a forcewide basis, these costs appear to be funded on a level-of-effort basis. No integrated effort has yet been undertaken to determine what factors drive costs in this category, and the allocation

Material Distribution. The cost of material distribution is the cost of manpower and material needed to fill requisitions for supplies, spares, and repair parts including the cost of receiving, unpacking, storage, inspection, and packing and crating. These costs are identified with program element 71111, Supply Depots/Operations. Resources for these activities appear to be programmed at a level of effort that is independent of weapon system force levels, and the factors that drive requirements in this area are not easily identified with weapon systems.

Material Management. Material management for a weapon system includes the cost of manpower and material needed to manage the procurement of supplies, spares, and repair parts and to maintain control and accountability of these assets. These costs are included in functions the Air Force calls "procurement operations" and "material management." Procurement operations consist of prime procurement and contract management. Prime procurement is accomplished by AFLC and consists of the negotiation, award, amendment, revision, and termination of contracts for procurement of electronic systems, spares, and modifications and overhauls. Contract management, which is performed by both AFLC and AFSC, consists of a variety of services that oversee contractor performance. Procurement operations are accounted for in program element 71113, Procurement Operations.

As defined by the Air Force, the functions of "material management" are: computation of requirements, provisioning, requisition processing, cataloging and standardization, and material issue and accountability. The costs of these activities are covered by program element 71112, Inventory Control Point Operations.

The activities covered in this category are organized around specific contract arrangements, equipment items, and spare parts. A few of these may be peculiar to one weapon system, but most of them are common to many, and no comprehensive procedure exists today to relate overall resource requirements in this area to weapon system characteristics. On a forcewide basis the level of effort devoted to these functions appears to be insensitive to weapon system force levels.

Technical Support. This item includes the cost of sustaining (service) engineering, technical data, and documents needed to perform sustaining engineering and maintenance on aircraft components and support equipment. The Air Force considers this function to be part of the material management function, which is covered in program element 71112, Inventory Control Point Operations.[11]

Second Destination Transportation

Second destination transportation for a weapon system includes: (1) transportation of weapon system repair parts from CONUS stock points to depot and base level maintenance activities, (2) round trip transportation of engines and engine components, ground support equipment, and reparable secondary items between depot maintenance facilities and operational units or CONUS stock points. Program element 78010, Second Destination Transportation, includes movement of material by commercial transportation, commercial contractual airlift within CONUS, and by Military Airlift Command and Military Sealift Command to overseas areas. Also included are the costs of port handling, stevedoring, and demurrage. Material moved includes general cargo, missiles, special weapons, munitions, exchange service items,

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rules that have been proposed for use in weapon system and life cycle costing are apparently not related to any practices or procedures used to set the budget and manning levels for these activities.

[11]DOD Handbook 7045.7, Vol. I, Book No. 5, p. I-7-2, August 15, 1972; DOD Appropriations for FY 1977, Part 3, pp. 228-229.

APO mail, and motion picture service items. Excluded is the cost of transporting material associated with PCS moves.[12]

The relationship between forcewide Second Destination Transportation costs and weapon system characteristics is not clear. The number of items to be transported depends on such factors as system reliability, maintenance concept, and basing posture; but budget levels for this category appear to be established at a constant level of effort. Hence, estimates of the Second Destination Transportation cost attributable to weapon system may have little relationship to the way in which resources are actually allocated and utilized.

Personnel Training and Support

Individual Training. This category covers the variable cost of personnel acquisition and training (identified with MFP 8), including recruit acquisition (program elements 81711 through 81714), recruit training (82711), ROTC (82727), service academy (82728), specialized training (82782), professional training (82783), and undergraduate pilot and navigator training (Flight Training, 82784). Costs included are trainee pay and travel costs, instructor pay, and all supplies, materials, equipment, and contracted services needed to conduct or support training. Annual training costs attributable to a weapon system represent the variable costs of initial training for personnel to replace those who (on the average) are expected to leave the Air Force each year, and advanced technical and professional training to sustain the skill levels required for the types of personnel required by the system. This category does not include aircrew training costs (assumed to be captured in CCT costs).

The cost of conducting a training program is driven by the number of personnel to be trained and by the techniques and procedures used to accomplish the training. The number of trainees is driven strongly by the weapon system's manpower requirements, but estimating those requirements is considered to be a separate task from that of estimating costs for this cost element.

Simulators for undergraduate flight training and replenishment spares for training aircraft are funded under the Aircraft Procurement appropriation. Other training costs are funded by the Military Personnel and O&M appropriations.

Health Care. This category includes the variable cost of medical support for deployed unit personnel, base maintenance personnel, base support personnel, and trainees, including medical personnel pay and allowances, cost of medical material, and the cost of all other supplies, materials, equipment, and purchased services needed to provide health care. Care in Defense Facilities (87711), Care in Non-defense Facilities (87713), and Other Health Activities (87714) are the three program elements with which these costs are identified.

PCS Travel. This item includes the cost of PCS moves for deployed unit personnel, base level maintenance personnel, installations support personnel, training personnel, and medical personnel. The program element Permanent Change of Station (88731) collects these costs for all Air Force military personnel.

[12]DOD Appropriations for FY 1977, part 3, p. 233.

Sustaining Investments

Replenishment Spares. This item includes the cost of procuring aircraft, support equipment, and training device spares and repair parts that are:

1. Investment items (reparable items that are centrally managed with individual item reporting), and
2. Either
   a. Replacements for condemned items, or
   b. Additions to inventory because of changing demand rates, obsolescence, or insufficient procurement of Initial Spares.

Because the definition with respect to inventory levels is by convention, analyses should assess total spares requirements—both initial and replenishment.

Modifications. This category includes the cost of modification kits and modification initial spares for aircraft, support equipment, and training equipment. The included modifications are those that are needed to achieve acceptable safety levels, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excluded are modifications that are undertaken to provide operational capability not called for in original design or performance specifications. The Modification and Modification Initial Spares costs elements of the Aircraft Procurement appropriation include modifications for all these purposes. The costs are usually identified with the PPE, but they may also appear in the CCT program element.

Replenishment Ground Support Equipment. This item includes the cost of replenishing the inventory of support equipment that is needed to operate or support aircraft and aircraft subsystems or support equipment, consisting of replacements for support equipment peculiar to the weapon system, which are funded under the Peculiar Support portion of Aircraft Procurement (if the aircraft is still in production) or under Common AGE (if the aircraft is out of production); and replacements for in-service support equipment common to more than one type of aircraft, which are accounted for under the Common AGE portion of Aircraft Procurement. Initial support equipment funded as either Common AGE or Peculiar Support are excluded. (See Support Equipment under Support Investment.) Common AGE costs shown for an aircraft PPE in the F&FP may include the cost of new whole simulators if they are to be procured after the aircraft is out of production. But normally, for a new aircraft system, all simulator costs would be included in the Support Investment LCC category (Peculiar Support cost element of Aircraft Procurement).

Training Ordnance. This category includes the cost of replacing or increasing stocks of ordnance expended by the operating unit during peacetime flying operations for the purpose of sustaining aircrew proficiency in weapons delivery techniques.

Munitions. Training munitions are funded by the Other Procurement appropriation. This cost appears to be entirely associated with general purpose forces and is accounted for in program element 27599, Munitions Training Items.

Missiles. Training missiles are funded by Missile Procurement and identified with program elements 27161, Tactical AIM Missiles, and 27162, Tactical AGM Missiles.

Appendix B

DEFINITIONS OF VARIABLES USED IN THE MODEL

Table B.1

INDEXES

Index	Parameter	Maximum Value
b	base	NB
c	two-digit work unit code	NWUC
i	LRU	NL
j	support equipment type	NSE
k	SRU	NS_p
p	part (LRU or SRU)	$NP = NL + \sum_{i=1}^{NL} NS_p$
s	inspection type	NINSP
u	operating unit	NU_b
w	work center	NWC
y	year of operation of system	NY

Asterisks denote input variables.

*AHCR	Airman health care rate, dollars per manyear
*$ALTAC_b$	The number of aircraft on alert at base b
*APA	The worldwide average annual pay and allowance rate for airmen
*APCSR	Airman PCS rate, dollars per manyear
*ARBUT	The Engine Automatic Resupply and Buildup Time, in months
ARGB	Mean number of demands for spare engines for each stockage point during the average engine resupply time
ARGD	Mean number of demands for spare engines during the depot repair cycle
$ART_{p,y,b}$	Average resupply time for part p at base b in year y
*AS	A dummy variable indicating that the subject aircraft either does (AS = 0) or does not (AS = 1) have an air superiority mission
*ATBO	Average time between engine overhauls; the average number of years between consecutive overhauls of an engine
$BCKORD_y$	The average number of backorders per item per base in year y

*$BCMH_{i,w}$	Bench check manhours, the number of manhours required for work center w to conduct a bench check of LRU i
*BCR_p	The base condemnation rate, the fraction of removed p items that are condemned at base level
$BEOQC_y$	The base level maintenance material cost for year y
$BO_{y,b}$	The average number of backorders outstanding at base b in year y
*BP	The number of months in the base engine repair cycle
BPQ	The base level pipeline quantity, the number of whole spare engines needed to fill the base level portion of the engine pipeline
$BSL_{p,y,b}$	The stock level at base b in year y for part p
*$BRT_{p,b}$	Base repair cycle time at base b, in days: the average repair time for all p items removed at base b and not condemned or sent on to the depot for repair
$BUE_{y,b}$	The number of unit equipment being supported at base b in year y
CAC_y	The cost of the aircrews in year y
$CBLMM_y$	The cost of base level maintenance manpower
$CCSE_y$	The cost of common support equipment in year y
$CDDM_y$	The cost of direct depot manpower in year y
$CDDME_y$	The cost of direct depot manpower for engine overhaul in year y
$CDDMEI_y$	The cost of direct depot manpower for exchangeable item repair in year y
$CDDMP_y$	The cost of direct depot manpower for programmed depot maintenance in year y
$CDDMSE_y$	The cost of direct depot maintenance for support equipment repair in year y
CDM_y	The cost of depot direct manpower in year y
CHC_y	The cost of health care in year y
$CIDM_y$	The cost of indirect depot manpower in year y
$CIDME_y$	The cost of indirect depot manpower for engine overhaul in year y
$CIDMEI_y$	The cost of indirect depot manpower for exchangeable item repair in year y
$CIDMP_y$	The cost of indirect depot manpower for programmed depot maintenance in year y
$CIDMSE_y$	The cost of indirect depot manpower for support equipment repair in year y
CIS_y	The cost of initial spares in year y
CIT_y	The total cost of Individual Training for year y
*CIVP	The worldwide average pay and benefit rate for civilian workers, dollars per manyear
$CMOD_y$	The cost of modifications in year y
$CMOM_y$	Miscellaneous Operations and Maintenance cost for base level maintenance in year y, including all costs in the Operations and Maintenance appropriation that are not accounted for in other categories
*CMRI	The Combined Maintenance Removal Interval, the average number of engine operating hours between engine removals
$COND_{p,y}$	The condemnation requirement for year y; the quantity needed to replace units that cannot be repaired at either base or depot levels
*CONF	Confidence level, the desired probability of satisfying all engine demands in a specified time (base or depot pipeline time)

$CPCS_y$	The cost of PCS moves in year y
$CPOL_y$	For year y, the cost of POL
$CPSE_y$	The peculiar support equipment investment cost in year y
$CREW_{y,b}$	The number of aircrew members at base b in year y
CRS_y	The cost of replenishment spares in year y
$CRSE_y$	The cost of common support equipment replenishment in year y
*CRT_b	The crew ratio, the number of crews required per UE
$CSA_{y,b}$	The number of Command Staff airmen at base b in year y
*$CSASQ_b$	The marginal number of Command Staff airmen per squadron at base b
*$CSAWG_b$	The marginal number of Command Staff airmen per wing at base b
$CSC_{y,b}$	The number of Command Staff civilians at base b in year y
*$CSCSQ_b$	The marginal number of Command Staff civilians per squadron at base b
*$CSCWG_b$	The marginal number of Command Staff civilians per wing at base b
CSE_y	The total support equipment investment cost in year y
$CSO_{y,b}$	The number of Command Staff officers at base b in year y
*$CSOSQ_b$	The marginal number of Command Staff officers per squadron at base b
*$CSOWG_b$	The marginal number of Command Staff Officers per wing at base b
*CSZ	The crew size, the number of personnel per crew
*CTI_s	The inspection interval for inspection type s in calendar months
CTO_y	The cost of Training Ordnance in year y
$CWMOM_y$	Miscellaneous Operations and Maintenance cost for a wing in year y, including all PPE costs in the Operations and Maintenance appropriation that are not accounted for in other categories
*DCR_p	The depot condemnation rate for component p, the fraction of items sent to the depot that are subsequently condemned
*DDFE	Direct depot manpower factor for engine overhaul, fraction of manpower that is direct
*DDFEI	Direct depot manpower factor for exchangeable item repair, fraction of manpower that is direct
*DDFP	Direct depot manpower factor for PDM, fraction of manpower that is direct
*DDFSE	Direct depot manpower factor for support equipment repair, fraction of manpower that is direct
$DDME_y$	Direct depot manpower for engine overhaul in year y
$DDMEI_y$	Direct depot manpower for exchangeable item repair in year y
$DDMP_y$	Direct depot manpower for programmed depot maintenance in year y
$DDMSE_y$	Direct depot maintenance for support equipment repair in year y
$DDR_{p,y,b}$	The daily demand rate for part p at base b in year y
$\Delta_{p,y}$	Delay function expressing the frequency with which the depot replacement time for part p exceeds the average order and shipping time during the year y
$DEOQC_y$	The cost of EOQ items demanded at depot level in year y
$DLHE_y$	The total number of depot direct labor hours to perform engine overhauls during year y
$DLHEI_y$	The total number of depot direct labor hours required to repair exchangeable items during year y
$DLHP_y$	The total number of depot direct labor hours to perform Programmed Depot Maintenance during year y

$DLHSE_j$	The total number of depot direct labor hours required to repair support equipment type j
*DLH/EIR_p	The average number of direct labor hours required to repair exchangeable item p
*DLH/EOH	The average number of direct labor hours to perform an engine overhaul
*DLH/PDM	The average number of direct labor hours to perform Programmed Depot Maintenance
*DLH/SER_j	The average number of direct labor hours required to repair support equipment type j
$DLY_{i,k,y,b}$	The expected delay in LRU i base repair due to a backorder on its kth SRU at base b during year y
DMC_y	The total material cost for year y associated with depot maintenance actions
*DMP	Depot maintenance productivity, available manhours per man per month
DOQ	The engine depot overhaul quantity, the minimum number of engines that provides the desired probability of satisfying all engine demands during the depot overhaul cycle
*DP	Depot engine repair cycle time, in months
*DRT_p	The average depot repair time, in days
$DS_{p,y}$	The depot stock level for part p in year y
$EIMC_y$	The consumable material cost in year y for exchangeable item repair
EIR_y	The number of exchangeable item repair actions in year y
EMC_y	The consumable material cost in year y for engine overhauls
EOH_y	The number of engine overhauls in year y
*EPA	Engines per application, the number of engines installed on each airframe
*$ERMH_w$	Engine removal manhours, the number of manhours for work center w involved in engine removal
*$ERPMH_w$	Engine repair manhours, the number of manhours for work center w involved in repair of a failed engine
*ERTS	The fraction of removed engines that are returned to serviceable condition by base maintenance
*EUC	The engine unit cost
*FAC	Average unit flyaway cost
$FAIL_{i,y,b,u}$	The number of failures of LRU i in unit u during year y at base b
*FDPM	The number of flying days per month
$FH_{y,b,u}$	The total number of monthly flying hours for unit u at base b in year y
FH/MO	Flying hours per month per aircraft
*FHI_s	The inspection interval in aircraft flying hours, for inspection type s
$FILL_y$	The average system fill rate in year y
$FLIMH_{y,b,w,u}$	The total number of manhours spent in flightline inspections, work center w on aircraft of unit u at base b in year y
$FR_{y,b}$	The fill rate for base b in year y
*GAE	Engine overhaul General and Administrative cost factor, dollars per direct labor hour
*GAEI	Exchangeable item repair General and Administrative cost factor, dollars per direct labor hour
*GAL/FH	Fuel consumption rate, gallons per flying hour
*GAP	PDM General and Administrative cost factor, dollars per direct labor hour

*GASE	Support equipment repair General and Administrative cost factor, dollars per direct labor hour
*IDFE	Indirect depot manpower factor for engine overhaul, fraction of manpower that is indirect
*IDFEI	Indirect depot manpower factor for exchangeable item repair, fraction of manpower that is indirect
*IDFP	Indirect depot manpower factor for PDM, fraction of manpower that is indirect
*IDFSE	Indirect depot manpower factor for support equipment repair, fraction of manpower that is indirect
$IDME_y$	Indirect depot manpower for engine overhaul in year y
$IDMEI_y$	Indirect depot manpower for exchangeable item repair in year y
$IDMP_y$	Indirect depot manpower for exchangeable maintenance in year y
$IDMSE_y$	Indirect depot maintenance for support equipment repair in year y
*$IMH_{i,w}$	In-place repair manhours, the number of manhours required for work center w to repair LRU i on-aircraft
*INV_y	The total inventory of aircraft in year y, including non-UE aircraft
ISA_y	The numbers of installations support airmen in year y
ISC_y	The numbers of installations support civilians in year y
*ISF	Installations Support cost factor, dollars per manyear
ISO_y	The numbers of installations support officers in year y
$ISOM_y$	Installations support miscellaneous O&M costs charged to BOS and RPM program elements
ISP_y	Installations support personnel costs charged to BOS and RPM program elements
*KAS	Fraction of sorties that are air superiority missions
*LHMFE	Labor hour material cost factor for engine overhaul, dollars per engine overhaul manhour
*LHMFEI	Labor hour material cost factor for exchangeable item repair, dollars per exchangeable item repair manhour
*LHMFP	Labor hour material cost factor for PDM, dollars per PDM manhour
*LHMFSE	Labor hour material cost factor for support equipment repair, dollars per support equipment repair manhour
*$LRMH_{i,w}$	The number of manhours required by work center w when LRU i is repaired other than by SRU replacement
$LRUD_{i,y,b}$	The expected delay for indentured LRU i at base b in year y because of a backorder of any of its SRUs
*LS	The number of engine stockage points
MA_y	The number of medical airmen in year y
*MCFE	Engine overhaul material cost factor, dollars per overhaul
*$MCFEI_p$	Depot repair material cost factor, fraction of item unit cost per item repair
*MCFP	PDM material cost factor, dollars per PDM
*$MCFSE_j$	Support equipment repair material cost factor, dollars per repair
*$MH/INSP_{s,w}$	The manhours per inspection for work center w for inspection type s
*MH/PF_w	The average number of work center w manhours per preflight inspection
*MH/PO_w	The average number of work center w manhours per postflight inspection
$MH/SOR_{y,b,w,u}$	The workload during year y for work center w at base b in support of unit u manhours per sortie

*MH/TF_w	The average number of work center w manhours per throughflight inspection
$MIMH_{y,b,w,u}$	The workload for work center w for all major inspections on unit u aircraft at base b in year y
$MMH_{y,b,w,u}$	The total workload for work center w for year y in support of unit u at base b
MO_y	The number of medical officers in year y
*MODF	Modifications cost factor, fraction of flyaway cost per year
*MOMF	PPE miscellaneous O&M cost factor
MTA_y	The number of maintenance airmen in year y
*MTAACQ	Maintenance airman acquisition cost, dollars per man
*MTATO	Maintenance airman turnover rate, fraction of the number of maintenance airmen that are replaced each year
*MTATRG	Maintenance airman training cost, dollars per man
*$MTBF_{p,y}$	The mean time between true failures, expressed in aircraft flying hours, for year y
MTC_y	The number of civilians in the maintenance organizations at base level in year y
*$NAA_{y,b,u}$	Number of alert aircraft in unit u at base b in year y
*NB	Number of operating bases
$NI_{y,b,s,u}$	The number of inspections of type s in year y at base b in support of unit u
*NINSP	The number of major inspection types
*NL	The total number of LRUs
NMA_y	The number of airmen not assigned to aircraft maintenance in year y
*NMAACQ	Nonmaintenance airman acquisition cost, dollars per man
*NMATO	Nonmaintenance airman turnover rate, fraction of the number of nonmaintenance airmen that are replaced each year
*NMATRG	Nonmaintenance airman training cost, dollars per man
*NP	The number of unique aircraft parts, including both LRUs and SRUs
NRO_y	The number of nonrated officers in year y
*NROACQ	Nonrated officer acquisition cost, dollars per man
*NROTO	Nonrated officer turnover rate, fraction of the number of nonrated officers that are replaced each year
*NROTRG	Nonrated officer training cost, dollars per man
*$NRTS_p$	Not reparable this station fraction, the fraction of removed items that are sent to the depot for repair
*NS_i	Number of SRUs in LRU i
*NSE	The number of types of support equipment
*NU_b	Number of deploying units operating in peacetime from base b (all aircraft from base b deploying to any one location are considered to belong to a single unit)
*NUL	Number of unindentured LRUs
*NWC	Number of work centers in base level maintenance
*NY	Number of years of weapon system operation
*OCE	Engine overhaul factor for other depot costs, dollars per direct labor hour
*OCEI	Exchangeable item repair factor for other depot costs, per direct labor hour
*OCP	PDM factor for other depot costs, dollars per direct labor hour

*OCSE	Support equipment repair factor for other depot costs, dollars per direct labor hour
ODC_y	Other depot maintenance cost (other than manpower and material costs) in year y
$ODCE_y$	Other depot maintenance cost (other than manpower and material costs) for engine overhauls in year y
$ODCEI_y$	Other depot maintenance cost (other than manpower and material costs) for exchangeable item repair in year y
$ODCP_y$	Other depot maintenance cost (other than manpower and material costs) for programmed depot maintenance in year y
$ODCSE_y$	Other depot maintenance cost (other than manpower and material costs) for support equipment repair in year y
$OFCRM_y$	The number of maintenance officers in year y
$OFFMH_{i,y,b,w,u}$	The off-aircraft workload for year y for work center w to maintain LRU i for unit u at base b
*OHCR	Officer health care rate, dollars per manyear
$ONMH_{i,y,b,w,u}$	The number of manhours required during year y at base b in work center w to perform unscheduled on-aircraft work on LRU i for unit u
*OPA	The worldwide average annual pay and allowance rate for officers
*OPCSR	Officer PCS rate, dollars per manyear
ORO_y	The number of rated officers other than pilots in year y
*OROACQ	Other rated officer acquisition cost, dollars per man
*OROTO	Other rated officer turnover rate, fraction of the number of nonpilot crew members that are replaced each year
*OROTRG	Other rated officer training cost, dollars per man
$*OST_{p,b}$	Order and shipping time for base b, in days
$OWA_{y,b}$	The number of airmen in the Other Wing Manpower category at base b in year y
$*OWASQ_b$	The marginal number of Other Wing Manpower airmen per squadron at base b
$*OWAWG_b$	The marginal number of Other Wing Manpower airmen per wing at base b
$OWC_{y,b}$	The number of civilian personnel in the Other Wing Manpower category at base b in year y
$*OWCSQ_b$	The marginal number of Other Wing Manpower civilians per squadron at base b
$*OWCWG_b$	The marginal number of Other Wing Manpower civilians per wing at base b
$OWO_{y,b}$	The number of officers in the Other Wing Manpower category at base b in year y
$*OWOSQ_b$	The marginal number of Other Wing Manpower officers per squadron at base b
$*OWOWG_b$	The marginal number of Other Wing Manpower officers per wing at base b
$*P_{i,k}$	The probability of SRU replacement, the probability that a failure of LRU i will be corrected by a replacement of its kth SRU
*PA	Base maintenance personnel availability, in available manhours per man per month

*$PAMH_{i,w}$	Preparation and access manhours for LRU i in work center w, the number of manhours required to gain access to LRU i and prepare to work on it
PDM_y	The number of aircraft PDMs in year y
$PDMF_y$	The fraction of the inventory to be scheduled for PDM in year y
*PDMI	The PDM interval; the average number of years between PDMs for a given aircraft
PFFH	Peak force flying hours, the maximum number of flying hours flown by the force in one month
$PF/YR_{y,b,u}$	The number of preflight inspections performed in year y on the aircraft of unit u at base b
$PL_{p,y,b}$	The base stockage quantity for part p at base b in year y that is needed to fill the resupply pipeline
PLT_y	The number of pilots in year y
*PLTACQ	Pilot acquisition cost, dollars per pilot
*PLTO	Pilot turnover rate, fraction of total number of pilots that are replaced each year
*PLTTRG	Pilot training cost, dollars per pilot
PMC_y	The consumable material cost in year y for programmed depot maintenance
*POLC/GAL	Fuel cost factor (dollars per gallon)
$PO/YR_{y,b,u}$	The number of postflight inspections in year y of the aircraft in unit u at base b
PPC	Number of pilots per crew
$PPEA_y$	The number of airmen in the primary program element
$PPEC_y$	The number of civilians in the primary program element
$PPEO_y$	The number of officers in the primary program element
$PR_{X,Y}$	The probability that X units are in resupply, given that demands have a Poisson distribution with mean Q
*PS	A base level safety stock parameter, expressed as a number of standard deviations (usually 1.0)
*$PSEQ_y$	The peculiar support equipment quantity procured in year y
*PSEUC	The average unit cost for peculiar support equipment
P1	The number of personnel on mobility status, approximated in MACO by the number of personnel in all munitions work centers except Mobility and Administration
P2	The number of military personnel authorized for all of munitions maintenance, approximated here as all munitions work centers except Administration and Mobility
P3	The number of authorizations for Missile Maintenance, Munitions Maintenance, Storage and Handling, Equipment Maintenance, and Inspection
P4	The number of personnel in the Missile Maintenance, Munitions Maintenance, and Storage & Handling work centers
$QART_{p,b,y}$	The mean quantity of part p demanded in year y at base b during a period of time equal to the average resupply time of that part at that base
*QPA_p	Quantity per aircraft, the number installed on each aircraft
$Q1_{p,y}$	The mean quantity of unindentured part p demanded in year y during a period of time equal to the depot repair time for that part

$Q2_{p,y,b}$	The mean quantity of SRU p demanded in year y during a period of time equal to the average resupply time for that part at base b
*$REPGEN_p$	Specialized Repair Activity reparable generation rate, demands per item operating hour
*RIP_p	Repair in place fraction, the fraction of failures of part p that are repaired on-aircraft
*$RRMH_{i,w,k}$	SRU replacement manhours, the number of manhours required by work center w to replace the kth SRU in LRU i
$RSB_{p,y}$	Recoverable spares buy, the quantity of part p that is purchased in year y
$RSC_{p,y}$	Recoverable spares cost, the cost of the recoverable spares buy of part p in year y
*$RTOK_p$	Re-test OK fraction, the fraction of part p removals for which failure cannot be verified by later recheck
$S_{y,b,u}$	The number of sorties flown in one month of year y by unit u at base b
$SECA_{y,b}$	The number of airmen in Security at base b in year y
*$SECASQ_b$	The marginal number of security airmen per squadron at base b
$SECO_{y,b}$	The number of officers in Security at base b in year y
*$SECOSQ_b$	The marginal number of security officers per squadron at base b
*$SEI_{j,y}$	The number of items of support equipment type j in the inventory in year y
*SEF_j	Support equipment fraction; the fraction of the inventory of type j support equipment that require depot repair in any year
$SEMC_y$	The depot level consumable material cost in year y for support equipment repair
$SER_{j,y}$	The number of support equipment repair actions at depot level in year y for equipment type j
*SE/UE	Support equipment replenishment factor, dollars per UE
*SL	Sortie length, flying hours per sortie
$SMH_{y,b,w,u}$	The servicing manhours for work center w at base b in year y in support of unit u
*SMH/FH_w	Servicing manhours per flying hour for work center w
*$SQ_{y,b,u}$	For year y, the number of squadrons in unit u deploying from base b
*SR	Sortie rate, sorties per aircraft per day
$SS_{p,y,b}$	Safety stock level for part p at base b in year y
$TDR_{p,y}$	Total daily demand rate for part p in year y
$TEOQC_y$	The total cost of base level maintenance material and depot maintenance material in year y
$TF/YR_{y,b,u}$	The number of throughflight inspections in year y on the aircraft of unit u at base b
TIS_y	The total installations support cost for year y
*TOCRW	Training ordnance cost per crew per year
$TOFFMH_{y,b,w,u}$	The total off-aircraft workload for work center w to support unit u at base b in year y
$TONMH_{y,b,w,u}$	The total unscheduled on-aircraft workload for work center w to support unit u at base b in year y
*TOUE	Training ordnance cost per UE per year
$TSL_{p,y}$	The total stock level for year y

$^*UE_{y,b,u}$	Number of unit equipment aircraft being supported in year y at base b in unit u
$^*UF_p$	Use factor, the ratio of operating hours to flying hours
$UNSMH_{y,b,w,u}$	The unscheduled workload in work center w at base b in year y to support unit u
$UOFCRM_{y,b,u}$	The officer manpower for unit u deploying from base b, for year y
$UOHSM_{y,b,u}$	The overhead and supervision manpower in year y for unit u deploying from base b
$^*UP_p$	The unit price of part p
$WCM_{y,b,w}$	The total direct maintenance manpower needed at base b in year y in work center w
$WCMNG_{y,b,w,u}$	The direct maintenance manpower needed at base b in year y in work center w because of the work center's support of unit u
WG_b	The number of wings on base b
$WOA_{y,b}$	The total number of airmen in Other Wing Manpower
$WOO_{y,b}$	The total number of officers in Other Wing Manpower
*YP	The last year of production

Appendix C

MACO EQUATIONS

This is a complete list of the equations used in applying MACO to a weapon system supported by a conventional maintenance organization, using detailed (i.e., LRU level) data. The cost equations are presented first, organized by cost element. These are followed by the equations for base level maintenance workload and for supply support effectiveness. Section IV discusses alternative equations for use with certain alternative maintenance organizational structures or with less detailed hardware data.

SUPPORT EQUIPMENT

$$CSE_y = CPSE_y + CCSE_y .$$

$$CCSE_y = 0.01(FAC) \sum_{b=1}^{NB} BUE_{1,b} , \text{ if } y = 1;$$

$$= 0.01271(FAC) \sum_{b=1}^{NB} BUE_{1,b} + 0.01(FAC) \sum_{b=2}^{NB} BUE_{2,b} , \text{ if } y = 2;$$

$$= 0.005(FAC) \sum_{t=1}^{y} \sum_{b=1}^{NB} BUE_{t,b}$$

$$+ 0.00271(FAC) \sum_{t=1}^{y-1} \sum_{b=1}^{NB} BUE_{t,b} , \text{ if } 2 < y \leq YP;$$

$$= 0.00271(FAC) \sum_{t=1}^{y-1} \sum_{b=1}^{NB} BUE_{t,b} , \text{ if } y > YP.$$

$$CPSE_y = PSEQ_y PSEUC .$$

INITIAL SPARES

$$CIS_y = \sum_{p=1}^{NP} RSC_{p,y} \qquad \text{for } y = 1, 2$$

$$= 0 \qquad \text{for } y > 2$$

$$p = NL + \sum_{n=1}^{i-1} NS_i + k$$

$$RSC_{p,y} = UP_p RSB_{p,y}$$

$$RSB_{p,y} = TSL_{p,y} - TSL_{p,y-1} + COND_{p,y-1}$$

$$\text{if } TSL_{p,y} - TSL_{p,y-1} > 0;$$

$$= \max\left[TSL_{p,y} - TSL_{p,y-1} + COND_{p,y-1},\ 0\right]$$

$$\text{if } TSL_{p,y} - TSL_{p,y-1} < 0.$$

$$TSL_{p,y} = DS_{p,y} + COND_{p,y} + \sum_{b=1}^{NB} BSL_{p,y,b}\ ,$$

$$BSL_{p,y,b} = PL_{p,y,b} + SS_{p,y,b}$$

$$PL_{p,y,b} = \left[\left(1 - NRTS_p - BCR_p\right)BRT_{p,b} + NRTS_p OST_{p,b}\right]DDR_{p,y,b}$$

$$DDR_{p,y,b} = \frac{(FH/MO)BUE_{y,b}QPA_p\left(1 - RIP_p\right)}{30MTBF_{p,y}\left(1 - RTOK_p\right)}$$

$$FH/MO = (SR)(SL)(FDPM)$$

$$SS_{p,y,b} = PS\sqrt{3PL_{p,y,b}}$$

$$DS_{p,y} = 30TDR_{p,y}\left(NRTS_p + BCR_p\right)$$

$$TDR_{p,y} = \sum_{b=1}^{NB} DDR_{p,y,b}$$

$$COND_{p,y} = 365TDR_{p,y}\left(BCR_p + NRTS_p DCR_p\right)$$

SPARE ENGINES

$$CSPE_y = (LS(BPQ) + DOQ)EUC, \qquad \text{if } y = 1$$

$$= 0.0, \qquad \text{otherwise;}$$

BPQ is the minimum value of X for which

$$\sum_{n=0}^{X} e^{-ARGB} \frac{ARGB^n}{n!} > CONF\ ,$$

where

$$ARGB = \frac{PFFH(EPA)}{LS(CMRI)} (ERTS(BP) + (1 - ERTS)ARBUT)$$

$$PFFH = (FH/MO)\max\left[\sum_{b=1}^{NB} BUE_{y,b}\right]$$

DOQ is the minimum value of X for which

$$\sum_{n=0}^{X} e^{-ARGD} \frac{ARGD^n}{n!} > CONF\ ,$$

where

$$ARGD = \frac{PFFH(EPA)}{CMRI}(1 - ERTS)DP.$$

AIRCREWS

$$CAC_y = \sum_{b=1}^{NB} CREW_{y,b}OPA$$

$$CREW_{y,b} = BUE_{y,b}CRT_bCSZ$$

COMMAND STAFF

$$CSO_{y,b} = CSOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSOWG_bWG_{y,b}$$

$$CSA_{y,b} = CSASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSQWG_bWG_{y,b}$$

$$CSC_{y,b} = CSCSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + CSCWG_bWG_{y,b} ,$$

POL

$$CPOL_y = \sum_{b=1}^{NB} 12BUE_{y,b}(FH/MO)(GAL/FH)(POLC/GAL)$$

SECURITY

$$SECO_{y,b} = SECOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u}$$

$$SECA_{y,b} = SECASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u}$$

OTHER WING OPERATIONS MANPOWER

$$OWO_{y,b} = OWOSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWOWG_b WG_{y,b}$$

$$OWA_{y,b} = OWASQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWAWG_b WG_{y,b}$$

$$OWC_{y,b} = OWCSQ_b \sum_{u=1}^{NU_b} SQ_{y,b,u} + OWCWG_b WG_{y,b}$$

WING MISCELLANEOUS O&M

$$CWMOM_y = MOMF \sum_{b=1}^{NB} (CREW_{y,b} + WOO_{y,b} + WOA_{y,b})$$

$$WOO_{y,b} = CSO_{y,b} + SECO_{y,b} + OWO_{y,b}$$

$$WOA_{y,b} = CSA_{y,b} + SECA_{y,b} + OWA_{y,b}$$

BASE LEVEL MAINTENANCE MANPOWER

$$CBLMM_y = MTA_y APA + OPA \sum_{b=1}^{NB} OFCRM_{y,b}$$

$$OFCRM_{y,b} = \sum_{u=1}^{NU_b} UOFCRM_{y,b,u}$$

$UOFCRM_{y,b,u}$ and $UOHSM_{y,b,u}$ are read from tables 12 through 15. $WCMNG_{y,b,w,u}$ is that portion of work center w manning at base b in year y that is needed because of the work center's support of unit u. The summation over u produces the total manning for the work center at base b in year y. The primary variables used in computing $WCMNG_{y,b,w,u}$ are sortie rate (SR), unit size ($UE_{y,b,u}$), and manhours per sortie ($MH/SOR_{y,b,w,u}$):

$$MH/SOR_{y,b,w,u} = \frac{MMH_{y,b,w,u}}{12(S_{y,b,u})}$$

where $S_{y,b,u}$ = (SR)($UE_{y,b,u}$)(FDPM). The equation for the workload MMH is given in the Base Level Maintenance Workload section below. Also used in the manning equations is total monthly flying hours:

$$FH_{y,b,u} = (FH/MO)UE_{y,b,u}$$

In this list of Base Level Maintenance Manpower estimating equations, the subscripts on WCMNG are omitted to simplify the equations. This should not be a problem, since each work center is addressed separately.

Chief of Maintenance

The critical requirement for each function is the greater of the peacetime and wartime requirements. The peacetime requirement is

$$WCMNG = \frac{2125.6 + 0.5032(FH)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	18	26
180	14	21
242	11	16

The wartime requirements are published in a separate classified document.

Quality Control

$$WCMNG = \frac{3477.2 + 0.7469(S)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	26	33
180	21	26
242	16	20

Maintenance Control

$$WCMNG = 4$$

Job Control

$$WCMNG = \frac{1082.7 + 1.143(FH)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	16	33
180	13	27
242	9	21

Plans and Scheduling

$$WCMNG = \frac{532.8 + 1.0813(S)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	6	17
180	5	15
242	4	12

Documentation

$$WCMNG = \frac{264.2 + 6.393(UE)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	2	8
180	2	7
242	2	5

Materiel Control

$$WCMNG = \frac{19.18S^{0.4269}}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	1	4
180	1	4
242	1	3

Maintenance Supply Liaison

$$WCMNG = \frac{505.8 + 1.013(S)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	6	17
180	5	15
242	3	11

Production Control

$$WCMNG = \frac{713.7 + 0.9658(S)}{PA}$$

This result is constrained by these limits:

PA	Lower Limit	Upper Limit
144	7	16
180	6	15
242	5	12

Flightline

$$WCMNG = 0.105(MH/SOR)^{1.312}SR^{1.605}UE^{0.925}(365.28/PA)$$

Inspection, Fuel Systems

$$WCMNG = 1.034(MH/SOR)^{0.370}SR^{0.617}UE^{0.613}(365.28/PA)$$

Alert Force

$$WCMNG = NAA$$

Machine Shop

WCMNG = 5 for combat aircraft

= 2 for reconnaissance aircraft

Metal Processing

WCMNG = 3 for combat aircraft

= 2 for reconnaissance aircraft

Structural Repair

$$WCMNG = 1.013(MH/SOR)^{0.875}SR^{1.575}UE^{0.563}(365.28/PA)$$

Corrosion Control

$$WCMNG = 0.92 + 0.14(UE)$$

Survival Equipment

$$WCMNG = 3.02 + 0.12(UE)$$

Non-destructive Inspection

$$WCMNG = 4.48 + 0.14(UE)$$

Jet Engine, Weapons Control

$$CMNG = 0.538(MH/SOR)^{0.908} SR^{1.484} UE^{0.730}(365.28/PA)$$

Repair & Reclamation

$$WCMNG = 1.016(MH/SOR)^{1.012} UE^{0.612}(365.28/PA)$$

Electrical, Pneudraulic, Instrumentation

$$WCMNG = 1.019(MH/SOR)^{0.890} SR^{1.413} UE^{0.537}(365.28/PA)$$

Environmental

$$WCMNG = 1.026(MH/SOR)^{0.410} UE^{0.501}(365.28/PA)$$

Egress

$$WCMNG = [2.641(MH/SOR) + 3.905(SR)](365.28/PA)$$

AGE Management

WCMNG is obtained from Table 10.

AGE Repair and Inspection

For reconnaissance aircraft, WCMNG is specified in Table 11.
For combat aircraft,

$$MH/SOR_{y,b,w,u} = \frac{MMH_{y,b,w,u}}{12(S_{y,b,u})}$$

$$WCMNG = 3.49 \frac{S}{PA} \quad \text{with conventional avionics}$$

$$= 6.20 \frac{S}{PA} \quad \text{with integrated avionics}$$

AGE Servicing, Pickup, and Delivery

For combat aircraft,

$$WCMNG = 4.44 \frac{S}{PA} \quad \text{with conventional avionics}$$

$$= 7.90 \frac{S}{PA} \quad \text{with integrated avionics}$$

WCMNG for reconnaissance aircraft is given in Table 11.

Communications

$$WCMNG = 1.054(SR)^{2.985}UE^{0.550}(365.28/PA)$$

Navigation

$$WCMNG = 1.016(UE)^{0.450}(365.28/PA) \quad \text{for reconnaissance aircraft}$$

$$WCMNG = 1.026(MH/SOR)^{0.410}UE^{0.501}(365.28/PA) \quad \text{for combat aircraft}$$

Electronic Countermeasures (ECM)

$$WCMNG = 0.246(MH/SOR)^{1.657}UE^{0.734}(365.28/PA)$$

Inertial Navigation

$$WCMNG = 0.308(MH/SOR)^{0.309}UE^{0.860}(365.28/PA)$$

Automatic Flight Control

$$WCMNG = 7.304(MH/SOR)^{0.425}SR^{2.010}(365.28/PA)$$

Photographic & Sensors

$$WCMNG = 1.011(UE)^{0.390}(365.28/PA) \qquad \text{for combat aircraft}$$

$$WCMNG = 1.026(UE)^{0.939}(365.28/PA) \qquad \text{for reconnaissance aircraft}$$

Precision Measuring Equipment Laboratory

$$WCMNG = 23$$

Avionics Shop

$$WCMNG = 1.116(MH/SOR)^{0.434}UE^{0.733}(365.28/PA)$$

Munitions Maintenance Commander and Munitions Services

$$WCMNG = 17$$

Weapons Loading

$$WCMNG = 4SQ + 2UE$$

Weapons Release, Gun Services, Missile Maintenance, Munitions Maintenance, Storage & Handling

$$WCMNG = SR(UE)[A + B(KAS) + C(1 - KAS)]$$

A, B, and C are defined for each individual work center in a separate classified document.

Munitions Supply Accountability and Munitions Control

$$WCMNG = 6.25 + 0.06(P4) + 2.38(AS)$$

P4 is the total manning for Missile Maintenance, Munitions Maintenance, and Storage and Handling.

Equipment Maintenance and Inspection

$$WCMNG = 0.12057(P4)$$

Munitions Maintenance & Storage

$$WCMNG = \frac{P3/(0.06646 + 0.001186(P3))}{PA}$$

P3 is P4 plus the additional manning for Equipment Maintenance and Inspection.

Munitions Maintenance Administration

$$WCMNG = \frac{2.01(P2)^{0.9889}}{PA}$$

P2 = total manning for all other munitions work centers except Munitions Maintenance Mobility.

Munitions Maintenance Mobility

$$WCMNG = \frac{[133.1 - 0.11(P1) + 0.0008048(P1)^2]}{PA}$$

P1 = total manning for all other munitions work centers except Munitions Maintenance Administration.

BASE LEVEL MAINTENANCE MATERIAL

$$BEOQC_y = -46.4 + 0.029 \sum_{p=1}^{NP} 365TDR_{p,y}\left(1 - BCR_p - NRTS_p DCR_p\right)UP_p$$

BASE LEVEL MAINTENANCE MISCELLANEOUS O&M

$$CMOM_y = MOMF\left(MTA_y + \sum_{b=1}^{NB} OFCRM_{y,b}\right)$$

INSTALLATIONS SUPPORT

$$TIS_y = ISP_y + ISOM_y$$

$$ISP_y = ISO_y OPA + ISA_y APA + ISC_y CIVP$$

$$ISOM_y = ISF(PPEO_y + PPEA_y + PPEC_y) + ISF(ISO_y + ISA_y + ISC_y)$$

$$ISO_y = 0.00312(PPEO_y + PPEA_y)$$

$$ISA_y = 0.12636(PPEO_y + PPEA_y)$$

$$ISC_y = 0.02652(PPEO_y + PPEA_y)$$

$$PPEO_y = \sum_{b=1}^{NB} (CREW_{y,b} + WOO_{y,b} + OFCRM_{y,b})$$

$$PPEA_y = MTA_y + \sum_{b=1}^{NB} WOA_{y,b}$$

$$PPEC_y = \sum_{b=1}^{NB} (MTC_{y,b} + CSC_{y,b} + OWC_{y,b})$$

DEPOT MAINTENANCE MANPOWER

$$CDM_y = CDDM_y + CIDM_y$$

$$CDDM_y = CDDMP_y + CDDME_y + CDDMEI_y + CDDMSE_y$$

$$CDDMP_y = DDMP_y CIVP$$

$$CDDME_y = DDME_y CIVP$$

$$CDDMEI_y = DDMEI_y\,CIVP$$

$$CDDMSE_y = DDMSE_y\,CIVP$$

$$DDMP_y = \frac{DLHP_y}{DMP}\,DDFP$$

$$DDME_y = \frac{DLHE_y}{DMP}\,DDFE$$

$$DDMEI_y = \frac{DLHEI_y}{DMP}\,DDFEI$$

$$DDMSE_y = \frac{DLHSE_y}{DMP}\,DDFSE$$

$$DLHP_y = PDM_y\,\frac{DLH}{PDM}$$

$$DLHE_y = EOH_y\,\frac{DLH}{EOH}$$

$$DLHEI_y = \sum_{p=1}^{NP} EIR_{p,y}\,\frac{DLH}{EIR_p}$$

$$DLHSE_y = \sum_{j=1}^{NSE} SER_{j,y}\,\frac{DLH}{SER_j}$$

$$PDM_y = INV_y PDMF_y$$

$$PDMF_y = 0 \qquad \text{for small } y$$

$$= \frac{1}{PDMI} \qquad \text{for large } y$$

$$EOH_y = \frac{(FH/MO)EPA \sum_{b=1}^{NB} BUE_{y,b}}{ATBO_y}$$

$$EIR_{p,y} = \left(\frac{(1 - RIP_p)NRTS_p \sum_{b=1}^{NB} \sum_{u=1}^{NU_b} FAIL_{p,y,b,u}}{RTOK_p} + (FH/MO)QPA_p UF_p REPGEN_p \right) (1 - DCR_p) \sum_{b=1}^{NB} BUE_{y,b}$$

$$SER_{j,y} = SEI_{j,y} SEF_j$$

$$CIDM_y = CIDMP_y + CIDME_y + CIDMEI_y + CIDMSE_y$$

$$CIDMP_y = IDMP_y CIVP$$

$$CIDME_y = IDME_y CIVP$$

$$CIDMEI_y = IDMEI_y CIVP$$

$$CIDMSE_y = IDMSE_y CIVP$$

$$IDMP_y = IDFP \frac{DLHP_y}{DMP}$$

$$IDME_y = IDFE \frac{DLME_y}{DMP}$$

$$IDMEI_y = IDFEI \frac{DLHEI_y}{DMP}$$

$$IDMSE_y = IDFSE \frac{DHLSE_y}{DMP}$$

DEPOT MAINTENANCE MATERIAL

Compute this cost element as either the cost of EOQ items demanded at depot level ($DEOQC_y$), a function of recoverable item failures, or as the material cost (DMC_y) associated with individual depot maintenance actions.

$$DEOQC_y = TEOQC_y - BEOQC_y$$

$$TEOQC_y = -29.9 + 0.039 \sum_{p=1}^{NP} 365TDR_{p,y}(1 - BCR_p - NRTS_p DCR_p) UP_p$$

$$DMC_y = PMC_y + EMC_y + EIMC_y + SEMC_y$$

$$PMC_y = DLHP_y LHMFP + PDM_y MCFP$$

$$EMC_y = DLHE_y LHMFE + EOH_y MCFE$$

$$EIMC_y = LMFEI(DLHEI_y) + \sum_{p=1}^{NP} UP_p MCFEI_p EIP_{p,y}$$

OTHER DEPOT MAINTENANCE COSTS

$$SEMC_y = LMHFSE(DLHSE_y) \sum_{j=1}^{NSE} (MCFSE)SER_j$$

OTHER DEPOT MAINTENANCE COSTS

$$ODC_y = ODCP_y + ODCE_y + ODCEI_y + ODCSE_y$$

$$ODCP_y = DLHP_y(GAP + OCP)$$

$$ODCE_y = DLHE_y(GAE + OCE)$$

$$ODCEI_y = DLHEI_y(GAEI + OCEI)$$

$$ODCSE_y = DLHSE_y(GASE + OCSE)$$

INDIVIDUAL TRAINING

$$CIT_y = PLT_y PLTO(PLTACQ + PLTTRG) + ORO_y OROTO(OROACQ + OROTRG)$$

$$+ NRO_y NROTO(NROACQ + NROTRG) + MTA_y MTATO(MTAACQ + MTATRG)$$

$$+ NMA_y NMATO(NMAACQ + NMATRG)$$

$$PLT_y = PPC \sum_{b=1}^{NB} BUE_{y,b} CRT_b$$

$$ORO_y = (CSZ - PPC) \sum_{b=1}^{NB} BUE_{y,b} CRT_b$$

$$NRO_y = PPEO_y - PLT_y - ORO_y$$

$$NMA_y = PPEA_y + ISA_y + MA_y - MTA_y$$

HEALTH CARE

$$CHC_y = OHCR(PPEO_y + ISO_y + MO_y) + AHCR(PPEA_y + ISA_y + MA_y)$$

$$+ MO_y OPA + MA_y APA + ISF(MO_y + MA_y)$$

$$MO_y = 0.0057(PPEO_y + PPEA_y + ISO_y + ISA_y)$$

$$MA_y = 0.0167(PPEO_y + PPEA_y + ISO_y + ISA_y)$$

PCS

$$CPCS_y = OPCSR(PPEC_y + ISO_y + MO_y) + APCSR(PPEA_y + ISA_y + MA_y)$$

REPLENISHMENT SPARES

$$CRS_y = \sum_{p=1}^{NP} RSC_{p,y} \qquad \text{for } y > 2$$

$$= 0 \qquad \text{for } y = 1, 2$$

MODIFICATIONS

$$CMOD_y = FAC(MODF) \sum_{b=1}^{NB} BUE_{y,b}$$

REPLENISHMENT SUPPORT EQUIPMENT

$$CRSE_y = (SE/UE) \sum_{b=1}^{NB} BUE_{y,b}$$

TRAINING ORDNANCE

$$CTO_y = \sum_{b=1}^{NB} BUE_{y,b}(TOUE + CR_b TOCRW)$$

BASE LEVEL MAINTENANCE WORKLOAD

$$MMH_{y,b,w,u} = UNSMH_{y,b,w,u} + FLIMH_{y,b,w,u} + MIMH_{y,b,w,u} + SMH_{y,b,w,u}$$

$$UNSMH_{y,b,w,u} = TONMH_{y,b,w,u} + TOFFMH_{y,b,w,u}$$

$$TONMH_{y,b,w,u} = \sum_{i=1}^{NL} \left(ONMH_{i,y,b,w,u}\right) + \frac{12(FH/MO)UE_{y,b,u}EPA\left(ERMH_w\right)}{CMRI}$$

$$ONMH_{i,y,b,w,u} = FAIL_{i,y,b,u}\left(PAMH_{i,w} + RIP_i IMH_{i,w} + (1 - RIP_i)RRMH_{i,w}\right)$$

$$+ \frac{FAIL_{i,y,b,u}\left(1 - RIP_p\right)\left(PAMH_{i,w} + RRMH_{i,w}\right)}{1 - RTOK_p}$$

$$= FAIL_{i,y,b,u}\left(PAMH_{i,w} + RIP_i IMH_{i,w} + (1 - RIP_i)\left(RRMH_{i,w} + \frac{PAMH_{i,w} + RRMH_{i,w}}{1 - RTOK_i}\right)\right)$$

$$FAIL_{i,y,b,u} = \frac{12(FH/MO)UE_{y,b,u}QPA_i}{MTBF_{i,y}}$$

$$TOFFMH_{y,b,w,u} = \sum_{i=1}^{NL} OFFMH_{i,y,b,w,u} + \frac{12(FH/MO)UE_{y,b,u}ERTS\left(ERPMH_w\right)}{CMRI}$$

$$OFFMH_{i,y,b,w,u} = \frac{FAIL_{i,y,b,u}\left(1 - RIP_i\right)}{1 - RTOK_i}\left(BCMH_{i,w} + (1 - NRTS_i - BCR_i)RMH_{i,w}\right)$$

$$RMH_{i,w} = LRMH_{i,w}\left(1 - \sum_{k=1}^{NS_i} P_{i,k}\right) + \sum_{k=1}^{NS_i}\left(RRMH_{p,w} + (1 - NRTS_p)RMH_{p,w}P_{i,k}\right)$$

$$FLIMH_{y,b,w,u} = \left(PF/YR_{y,b,u}\right)\left(MH/PF_w\right) + \left(TF/YR_{y,b,u}\right)\left(MH/TF_w\right)$$

$$+ \left(PO/YR_{y,b,u}\right)\left(MH/PO_w\right)$$

$$PF/YR_{y,b,u} = (365.)UE_{y,b,u} \qquad \text{if } SR \geq 1.0$$

$$= (365.)UE_{y,b,u}\, SR \qquad \text{if } SR < 1.0;$$

$$PO/YR_{y,b,u} = (365.)UE_{y,b,u} \qquad \text{if } SR \geq 1.0$$

$$= (365.)UE_{y,b,u} SR \qquad \text{if } SR < 1.0;$$

$$TF/YR_{y,b,u} = (365.)UE_{y,b,u} SR - \left(PO/YR_{y,b,u}\right)$$

$$= (365.)UE_{y,b,u}(SR - 1.0) \qquad \text{if } SR \geq 1.0$$

$$= 0.0 \qquad \text{if } SR < 1.0.$$

$$MIMH_{y,b,w,u} = \sum_{s=1}^{NINSP} NI_{y,b,s,u}\left(MH/INSP_{s,w}\right) ,$$

$$NI_{y,b,s,u} = \frac{12UE_{y,b,u}(FH/MO)}{FHI_s} \text{ , or}$$

$$NI_{y,b,s,u} = \frac{12UE_{y,b,u}}{CTI_s}$$

$$SMH_{y,b,w,u} = 12UE_{y,b,u}(FH/MO)\left(SMH/FH_w\right)$$

SUPPLY SUPPORT EFFECTIVENESS

The three measures of supply effectiveness are:

$$FILL_y = \frac{1}{NB} \sum_{b=1}^{NB} FR_{y,b}$$

$$FR_{y,b} = \frac{1}{NP} \sum_{p=1}^{NP} \sum_{X=1}^{BSL_{p,y,b}} PR(X;QART_{p,y,b})$$

$$BCKORD_y = \frac{1}{NB} \sum_{b=1}^{NB} \frac{BO_{y,b}}{\sum_{p=1}^{NP} DDR_{p,y,b}}$$

$$BO_{y,b} = \sum_{b=1}^{NB} \sum_{X>BSL_{p,y,b}}^{\infty} (X - BSL_{p,y,b}) PR(X;QART_{p,y,b})$$

$$FNORS_y = \sum_{b=1}^{NB} \sum_{c=0}^{\infty} \frac{1 - PNORS_{c,y,b}}{BUE_{y,b}}$$

$$PNORS_{c,y,b} = \prod_{p=1}^{NP} \sum_{X=1}^{LIM} PR(X;QART_{p,y,b}) \qquad \text{where } LIM = BSL_{p,y,b} + QPA_p C$$

Each of these measures uses

$$QART_{p,y,b} = DDR_{p,y,b} ART_{p,y,b}$$

and the functional form

$$PR(X;Q) = \frac{e^{-Q} Q^X}{X!}$$

QART is derived from the average resupply time ART. For SRUs and unindentured LRUs this is given by

$$ART_{p,y,b} = (1 - NRTS_p - BCR_p)BRT_{p,b} + (NRTS_p + BCR_p)(OST_{p,b} + \Delta_{p,y}DRT_p)$$

$$\Delta_{p,y} = \frac{1}{Q1_{p,y}} \sum_{X=DS_{p,y}+1}^{\infty} (X - DS_{p,y})PR(X;Q1_{p,y})$$

$$Q1_{p,y} = DRT_p TDR_{p,y}$$

For indentured LRUs the average resupply time is

$$ART_{p,y,b} = (1 - NRTS_p - BCR_p)(BRT_{p,b} + LRUD_{p,y,b})$$

$$+ (NRTS_p + BCR_p)(OST_{p,b} + \Delta_{p,y}DRT_p)$$

$$LRUD_{i,y,b} = \frac{\sum_{k=1}^{NS_i} DDR_{p,y,b}DLY_{i,k,y,b}}{\sum_{k=1}^{NS_i} DDR_{p,y,b}}$$

$$DLY_{i,k,y,b} = \frac{1}{DDR_{p,y,b}} \sum_{X=BSL_{p,y,b}+1}^{\infty} (X - BSL_{p,y,b})PR(X;Q2_{p,y,b})$$

$$Q2_{p,y,b} = TDR_{p,y}ART_{p,y,b}$$

Appendix D

COMPARISON OF COST ELEMENT STRUCTURES

MACO uses a set of cost elements suggested by the CAIG shortly before development of MACO began. Since then, the CAIG has published a new cost development guide with a somewhat different structure.[1] The current CAIG elements are listed in Table D.1. The current guide covers Operating and Support Cost (equivalent to MACO's Operations and Support cost) but does not address the initial investment in support resources that is covered by MACO as Support Investment. Within O&S, individual cost elements in the guide differ from individual MACO cost elements both in definition and in the scheme of aggregation. Thus, cost elements in MACO will not, in some cases, cover the same items as cost elements with the same names in the CAIG guide. A comparison of the two cost structures is described below.

Labor and material costs are combined in MACO for Wing Operations and Base Level Maintenance activities, where the CAIG guide keeps personnel costs separate from the cost of material. The cost elements under Wing Operations and Base Level Maintenance in MACO, with one exception, are restructured under Unit Mission Personnel and Unit Level Consumption in the guide. For example, Wing Operations-Aircrews corresponds exactly to Unit Mission Personnel-Aircrew, and Wing Operations-Command Staff, Security, and Other are all collected together in the CAIG Unit Mission Personnel-Other element. The exception is Miscellaneous O&M cost. The guide collects all such costs, from all activities, in a single cost element under Indirect Personnel Support.

The two cost structures use the term Installation Support somewhat differently. In MACO, it includes personnel costs and Miscellaneous O&M costs but excludes all medical costs (which are included under Personnel Support and Training). The related cost element in the CAIG guide is Installation Support Personnel. Medical personnel costs are included, but miscellaneous O&M costs are not.

The two Depot Maintenance cost elements include the same manpower and material costs, although the CAIG structure collects these costs by type of maintenance activity. The MACO equations as presented are directly applicable to the four primary activities: airframe rework, engine overhaul or rework, component repair, and support equipment repair. These equations can also be applied to software maintenance and modification installations if the cost estimator can supply appropriate data. Two other activities included in the CAIG guide, Other Depot maintenance and Contracted Unit Level Support, are not covered by the MACO equations. Except for these two activities, the formulation of MACO allows depot maintenance costs to be aggregated as manpower and material subtotals or as activity subtotals corresponding to the CAIG guide.

The MACO elements Depot Supply and Second Destination Transportation are collected by the CAIG into an element called Depot Non-Maintenance.

The MACO cost element Personnel Support and Training does not exist in the CAIG structure, but all of its subelements do. Individual Training is equivalent to the CAIG ele-

[1]Office of the Secretary of Defense, Cost Analysis Improvement Group, *Aircraft Operating and Support Cost Development Guide*, 15 April 1980.

ment Personnel Acquisition and Training. Health Care is partly under Installation Support Personnel and partly under Medical O&M Non-Pay (part of Indirect Personnel Support). PCS costs are also under Indirect Personnel Support in the CAIG cost structure.

The Sustaining Investment cost elements are similar in concept, but their contents are slightly different in detail. Replenishment Spares includes SE spares in MACO but not in the CAIG categorization. The CAIG puts SE spares into the Replacement SE cost element, which includes only the cost of the SE itself in MACO. Training ordnance is part of Sustaining Investment in MACO, but part of Unit Level Consumption in the CAIG guide. The guide includes a category of Other Recurring Investment that is not in MACO but there are no examples of what may typically be included. It is unlikely that this will be a large element of cost in most analyses.

Table D.1

CAIG OPERATING AND SUPPORT COST ELEMENTS

Unit Mission Personnel
Aircrew
Maintenance
Other
Unit Level Consumption
Petroleum, oil and lubricants
Maintenance material
Training ordnance
Depot Level Maintenance
Airframe rework
Engine rework
Component repair
Support equipment
Software
Modifications
Other depot
Contracted unit level support
Installation Support Personnel
Base operating support
Real property maintenance
Medical
Indirect Personnel Support
Miscellaneous Operations and Maintenance
Medical O&M non-pay
Permanent change of station
Temporary additional duty pay[a]
Depot Non-maintenance
General depot support
Second destination transportation
Personnel Acquisition and Training
Sustaining Investment
Replenishment spares
Replacement support equipment
Modification kits
Other recurring investment

[a]Primarily for Navy use.

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